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27th ANNUAL TECHNICAL SYMPOSIUM

1990

ASSOCIATION OF SCIENTISTS AND ENGINEERS
ASE
NAVAL SEA SYSTEMS COMMAND

CHALLENGES OF THE NINETIES — ACCOMPLISHING MORE WITH LESS

WEDNESDAY, MAY 23, 1990
SHERATON CRYSTAL CITY HOTEL
ARLINGTON, VIRGINIA

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ERRATA SHEET

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ORDNANCE INDUSTRIAL AND FACILITY MANAGEMENT

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Abstract

In 1985 the Secretary of the Navy had a management analysis done of the Navy Industrial Fund (NIF) program. Results of the study of the Ordnance NIF (ORD-NIF) were presented early in 1986 and contained findings and recommendations in the areas of organization, engineering, operations, materials management, financial management and management information systems. It was projected that the eleven ORD-NIF activities identified in the report could save between 250 and 300 million dollars over a five year period by implementing better business practices, including some from private industry.

As a result of the recommendations in the study many initiatives were undertaken in the industrial and facility management area which provided cost savings through increased productivity and quality improvement. Initially these efforts were on an individual activity basis utilizing the traditional cost reduction/savings goal approach.

Late in 1987 the focus of the program was changed to provide an Ordnance community direction. A Corporate Long Range Business Plan was developed through activity participation in a Board of Directors (BOD). Community pilot programs were initiated under the BOD with roll out of concepts to the entire community. All of these initiatives are directed toward improved productivity and support to the ORD-NIF customers. To date, ORD-NIF is ahead of the original plan to meet a 300 million dollar savings target.

In 1989, a Total Quality Management approach was adopted to ensure the ORD-NIF community continues moving in a positive direction.

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Introduction

The highly successful management improvement effort within the Navy's Ordnance Industrial Activities has made significant changes since its beginning in 1986. This effort will be reviewed highlighting a transition from a traditional dollar savings/cost reduction program to one that has begun to embrace many of the basic precepts of Total Quality Management (TQM). The Naval Industrial Fund (NIF) financial management concept, composition of activities involved, early history of the improvement effort, current initiatives, program successes and the vision for the future will be reviewed.

The Naval Industrial Fund

In 1949 the Naval Industrial Fund (NIF) was created to fund Navy-owned industrial and commercial activities, such as Navy shipyards, aviation depots, public works centers and ordnance activities. These activities are part of the mobilization capacity of the Navy and produce products or services which are "bought" by customers

(the Navy, the other services and civilian government agencies). It is important to understand that NIF is a revolving working capital fund, not an organization.

The objectives of the Naval Industrial Fund were to:

- consolidate the operation and fiscal responsibility under single management
- establish business-like management and financial operations in industrial and commercial type activities
- establish buyer-seller relationships between NIF activities and their customers
- promote common use among NIF activities of available facilities and inventories
- provide a method to compare operating results of similar activities within DOD and in private business.

SECNAV Industrial Fund Study

Over the 30 year history of NIF, the Navy has tried various initiatives to improve cost and productivity by changing the financial management operations and information systems of the NIF activities. The activities themselves tried various things to improve their situation. Most of these efforts failed to bring about long-lasting improvements. The main reason for this was that most of these initiatives were cost avoidance measures which did not address the underlying causes of the problems. Productivity decreased, costs rapidly increased, facilities and equipment deteriorated and became obsolete, backlogs increased and their mobilization ability was jeopardized.

For these reasons, in 1984, the Secretary of the Navy directed that an assessment of the NIF activities be conducted to determine what the problems were, to compare their practices against private industry and to provide recommendations for improvement. A management consulting firm with expertise in the public and private sector was hired to perform these assessments. Each type of activity in the NIF was studied separately as a group. Figure 1 shows the groups studied. The results of these studies became the basis for the Naval Industrial Improvement Program (NIIP).

Naval Industrial Improvement Program

The NIIP was charged with introducing and institutionalizing change in two key areas:

- Centrally administered rules and procedures that hamper the efficiency of individual NIF activities; and
- Work methods, procedures and processes that impede efficiency and operational control within the industrial activities.

The NIIP is basically a resource for NIF activities, providing technical assistance and facilitation in implementing sound business practices. The principle difference between NIIP and previous improvement initiatives is its focus on operations instead of simply reducing budgets. If operations can be improved, then dollar savings will follow.

The consultants visited the field activities and the headquarters elements responsible for the field activity management. They collected information at headquarters and at the field activities through structured interviews, observations and reviews of written material. This material was then subjected to a thorough analysis and the initial results of the NIIP study for each group was briefed to SECNAV and to senior activity management.

The Naval Ordnance Industrial Activity Group

The final SECNAV directed study in late 1985 was of the Ordnance Group. This Group comprises eleven separate commands with widely varing missions. The diversity of effort in the Group presented some major problems to the contractor teams as they moved from activity to activity. The group workforce is predominantly civilian having a total of 22,000 employees and an annual budget of $1.5 billion. Figure 2 shows the ordnance activity revenue distribution by function. Figure 3 shows the location of these activities. These 11 activities have work from more than 300 sponsors, the majority of which are from NAVSEA. Figure 4 shows the workload percentage by customer. Field activity management within NAVSEA rests with SEA 06G, Combat Systems Field Operations and Ordnance Support Group.

ORD-NIF Study Results

Initial results of the contractors study of the Ordnance Group were presented in February 1986 to a meeting of the Commanding Officer and Senior Civilian from each of the eleven ORD-NIF activities as well as key personnel from NAVSEA.

There were 89 recommendations contained in the report in six functional areas; organizational, engineering, operations, materials management, financial management, and management information systems. These findings and recommendations evolved from two main issues.

- The ordnance-NIF activities operate without a clearly articulated corporate strategy, and
- Major resource costs are not adequately controlled.

The study estimated that cost savings of between $250 and $300 million would result from implementing the recommendations. These projected savings were in five areas as shown in Figure 5.

Based on the study recommendations NAVSEA committed to save $300M over a five year period beginning with FY 1986. The savings were to be realized on a FY basis as shown in Figure 6. The five individual areas of savings were translated into the target goals for each of the eleven ORD-NIF Commands as shown in Figure 7. In April 1986 each of the eleven commands was directed to initiate efforts to achieve the savings goals with performance to be measured against their FY 1985 actual.

To develop a plan of action for the 89 recommendations an ADHOC NIIP steering team was convened in NAVSEA with senior representatives from a number of the field activities. This Team reviewed the entire report with contractor study team members, assigned appropriate action - field or headquarters - for each recommendation and worked with headquarters personnel on plans to implement those assigned to NAVSEA headquarters.

NAVSEA endorsed the team report and in May 1986 the 89 recommendations were forwarded to all the field activities with guidance to implement the recommendations assigned to Field Activities.

Phase I - Individual Activity Effort

Following publication of the initial guidance and goals, individual activities were left to develop their own programs for implementation and savings achievement. Semiannual reviews were scheduled as part of the ORD-NIF CO Conference. Each activity Commanding Officer made a 30 minute review of actions taken, accomplishments, problem areas, and savings achieved. There was considerable interaction between commands and with SEA 06 Flag personnel during these presentations.

Most of the effort in the Field Activities was directed, during this phase, toward traditional cost reduction techniques. Application of IE methods and standards techniques, establishment of productivity measures, and expanded cost control reports were utilized in the direct labor industrial operations. Zero base analysis organizational/staffing studies and executive review board techniques were applied to the indirect and overhead cost areas. In addition the Asset Capitalization Program (ACP) was utilized to greatly expand use of office automation equipment. These efforts resulted in some very impressive initial savings.

In headquarters, efforts were directed toward strengthening guidance and direction from NAVSEA to the Field Activity. NAVSEA 06G was reorganized to provide more directly aligned Field Activity Management and the Workload Management Information System was enhanced.

Another part of the early implementation effort was the identification of each activities unique work areas, facilities, and work skill base to be established as a Center of Excellence (COE). The COEs were refined through an iterative process and finally published as a NAVSEA instruction. Figure 8 identifies some representative COEs for the three types of ordnance activities; weapons stations, technical centers, and combat systems engineering centers.

In February 1987 the original NIIP Steering Team was asked to visit each activity to review their programs and validate savings dollar figures. The original team was augmented by a Financial Validation Team consisting of Field Activity Comptrollers and the senior Financial Officer in SEA 06. The team's mission was: to validate the savings reported by the field activities by reviewing the cost savings documentation; to review program implementation, making recommendations to the CO; and to pass along good ideas from other activities. Cost reductions had to be fully documented to be allowable as legimate savings. Figure 9 shows the goals and validated savings during phase I, FY 86 and 87.

Phase II Corporate Effort

In July 1987, as the improvement program neared the end of its second fiscal year it became apparent that a coordinated corporate approach would be necessary if the successes to date were to be continued and improvements institutionalized. A strategy was evolved during numerous discussions with personnel who had been active in the program from its inception as well as personnel who had been working with other Navy Industrial Communities (i.e., shipyards, aviation depots and public works centers). Figure 10 shows the basic framework for this strategy. First, a Long Range Business Plan needed to be developed for the Ordnance Community. This plan would articulate the corporate strategy setting goals and objectives. Secondly, a number of improvement

projects would be initiated to analyze processes, set performance indicators and put in place methods for continuous process improvement. Thirdly, the Management Informations Systems would be given a major overhaul to provide responsive feedback to supervisors on indicators and process performance. Each of these efforts will be generally outlined spotlighting approaches which set the framework for a Total Quality Management Program.

Long Range Business Plan

Although some individual Ordnance activities had strategic or long range plans, there was no ordnance corporate plan in July 1987. To develop the ORD-NIF Long Range Business Plan a significant change in program direction was instituted. Rather than develop the plan with headquarters staff, as was done with the original savings goals, active invoivement of the Field Activities was incorporated through a Board of Directors (BOD). The Board of Directors (BOD) consists of the Commanding Officers and Technical Director/senior civilian of each ordnance activity in conjunction with NAVSEA 06G.

The first BOD meeting was held in September 1987, and the final LRB plan published in January 1988 after a series of meetings. The BOD continues to meet two times per year, making updates and modifications to the plan as necessary. The Plan specifies the goals and objectives which focus on institutionalizing changes and making fundamental improvements in operations.

Long range business planning provides a system to form basic strategies that will guide our activities'operations and management to meet future changes in their business environment. Some of the long range plans may not be fully implemented until decades in the future. The long range planning process also has created a sense of unity among the ordnance NIF activities, many of which have widely diverse functions. In some ways, the planning process is more important than the plans themselves.

As one of the NIIP initiatives, planning assistance was provided to four activities that did not have individual strategic plans. This effort has enabled the activities to carry out their responsibilities and missions in a more businesslike manner. The planning process has been effective at these activities in improving communications and mutual problem solving among the individual department.

Process Improvement Projects

The strategy utilized with the various Process Improvement Projects was to select one Field Activity for accomplishment of a specific improvement task. These pilot tasks would concentrate in-house personnel resources, contractor expertise and community support to develop an approach and test results. Successful techniques would be rolled out to subsequent activities being facilitated by experienced team members from the pilot activity. In this way new ideas, concepts and approaches could be refined at a pilot facility before roll out.

The approach selected for application to the four major business lines within ORD-NIF has been nicknamed "PIMS" - Performance Indicator Measurement System. PIMS involves documentation of the process, development of indicators at critical steps in the process, collection of indicator data, improvement of the process and measurement of indicator changes. A key component of this effort was involvement of all supervisors connected with the process to define the process, to select indicators they required to monitor their piece of the process, to develop process improvements and to measure results.

Pilot projects were initiated in each of the four major business lines, Receipt Storage Segregation and Issue (RSSI), Intermediate Maintenance Activity (IMA), Depot level maintenance (DLM), and engineering. The PIMS effort in Engineering at NSWSES Port Hueneme has been the most challenging since little help is available from prior work in either the public or private sector. In the IMA business line the Maintenance of Air Launched Missiles was selected and the Program sponsor, NAVAIR, has been an active participant.

In the support area the BOD identified three major areas which provided high overhead cost and continual crisis needing top management attention. These three were Procurement, Material Management (both requirements determination and inventory management) and Public Works. The Public Works Department improvement project was initiated jointly with NAVFAC calling upon ideas, concepts and techniques found successful in their Public Works Center effort. Figure 11 shows the current status on the various NIIP Projects and activities involved.

Information Architecture Design

The key ingredient in monitoring improvements and process changes is the Management Information System. ORD-NIF was plagued with major problems in this area as noted in the original 1985 study. Although some effort had been made toward improvement in some subsystems areas the overall picture was one of confusion early in 1988. Outside "stovepipe systems" and hardware had been forced on the community, multiple data bases ex-

isted with similar information and major systems were geared to provide information desired by outside organizations and not useful to local process managers.

The logical solution was to develop a complete Information Architecture and begin the tedious task of slowly restructuring the systems to meet local management requirements. Use of commercially available software, where possible, sharing of databases and systems communications are key precepts for this project. Development of the initial pilot is still underway at two activities with completion targeted for the end of FY 1990.

Results to date

The results of the NIIP for the ordnance community over the past four years has been excellent. The real benefits have been to our customers who have received improved quality products, lower costs and greater value for their money. Figure 12 shows savings results to date against the original goal. Figure 13 shows the impact of efforts to reduce indirect staffing with the additional resources applied to elimination of the large backlog that existed in 1985.

The traditional cost reduction approach that NIIP started with is transitioning into a continuous analysis and improvement effort within the Total Quality Management arena. The following changes in program approach made during Phase II provide a good introduction to a fully implemented TQM Program of the future:

Customer focus
Process analysis
Employee involvement
Continuous improvement
Cost and quality emphasis
Communications between all levels
Sponsor involvement in improvement

Phase III TQM

Dr. Deming's fourteen points of quality management are as much a management philosophy as they are a quality improvement method. Management must understand the principles and lead the way to their implementation. To ensure that the Ordnance community continues its progress toward increased service to its customers and implementation of better business practices, a number of changes have been undertaken so that continuous improvement will become a permanent part of our daily operations.

The cornerstone of Deming's management philosophy is that long-term success depends on satisfying customers. This means that management has to keep its focus on customers. To do this we have established a Business Development Office (BDO) with a strong customer focus manned mainly by Field Activity personnel on developmental assignments. The mission is to assure that the Ordnance Community is responsive to current and future customer demands and to promote the Ordnance Activities COEs.

We have started a quarterly newsletter called "Ordnance Improvements." It will document improvement successes, credit activities that have produced them, share common problems, highlight innovative solutions to problems, and provide feedback on efforts to make continuous quality improvements an everyday part of activity operations.

Local activity TQM Programs are being actively encouraged and supported. The key here is that each activity was allowed freedom to implement a program designed to meet their specific needs and situations Each CO reviewed his TQM Program during the recently held Spring 1990 BOD.

The transition started by the above actions will not happen overnight. Dr. Deming points out that true change takes years, and even decades, to be incorporated into organizations, and as large and as complex as the ordnance community is, this is particularly true.

We are committed to the goal of TQM philosophy because it will lead to increased productivity, efficiency, quality products and a competitive position for new or renewed business. Figure 14 shows the ORD-NIF Vision - Our Target.

Bibliography

Deming, W. Edwards, Out of the Crisis. Massachusetts Institute of Technology, Center for Advanced Engineering Study. Cambridge, MA. 1986

The Naval Industrial Improvement Program - Initiatives: 1985-1986. October 1989.

Management Analysis of the Navy Industrial Fund Program - Ordnance Field Activities Review Report. July 1986.

NIF GROUPS STUDIED

* HEADQUARTERS
* SHIPYARDS
* NARFs
* ORDNANCE/WEAPON STATIONS
* LABS
* PWCs
* NAVDAC

Figure 1

REVENUE DISTRIBUTION

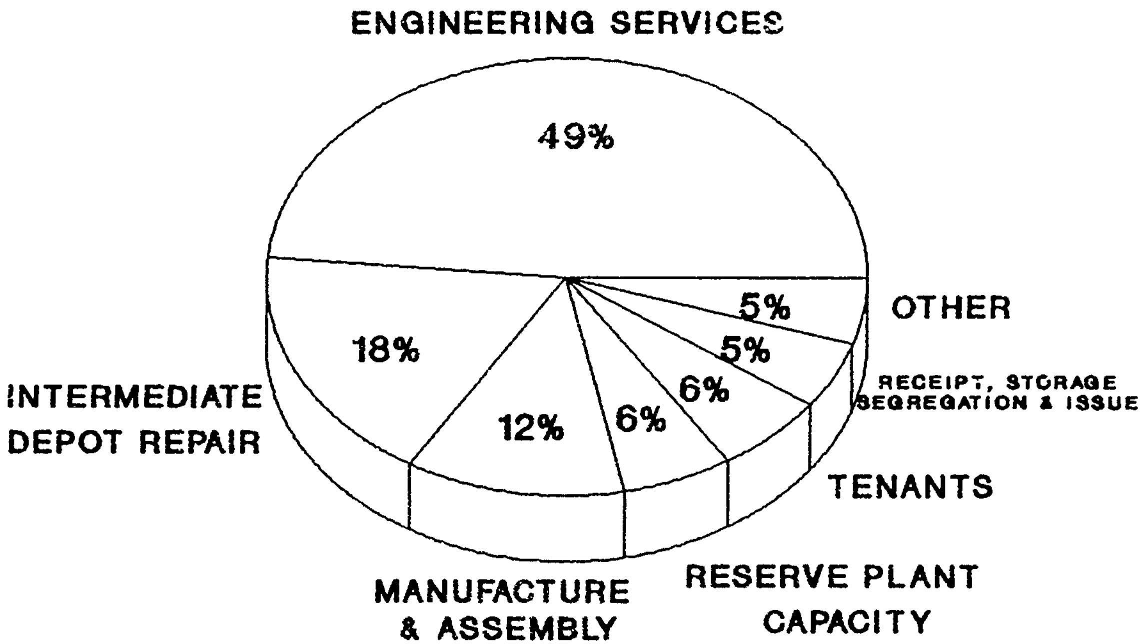


Figure 2

NAVSEA
WEAPONS & COMBAT SYSTEMS
FIELD ACTIVITIES
(NIF)

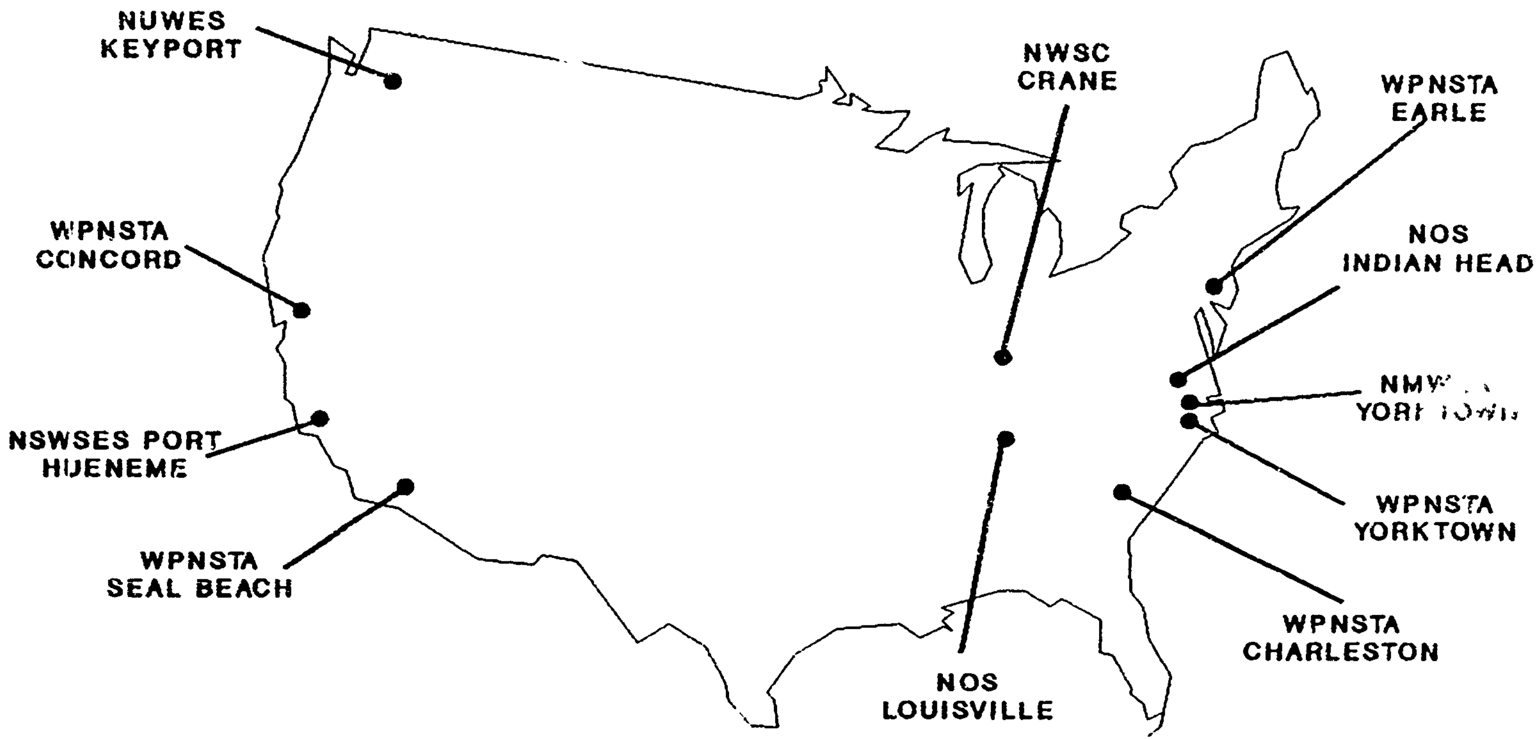


Figure 3

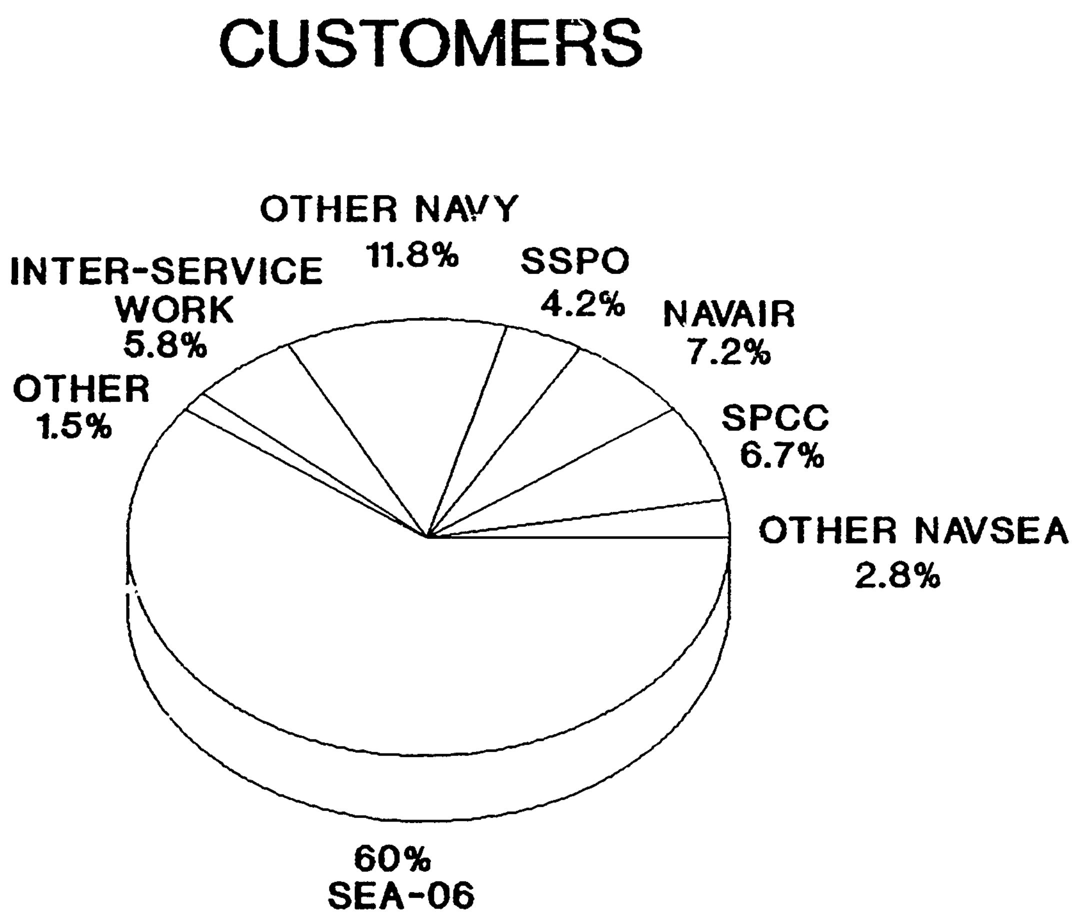

CUSTOMERS
OTHER NAVY 11.8%
SSPO 4.2%
NAVAIR 7.2%
SPCC 6.7%
OTHER NAVSEA 2.8%
60% SEA-06
OTHER 1.5%
INTER-SERVICE WORK 5.8%

Figure 4

PROJECTED SAVINGS

IMPLEMENTING RECOMMENDATIONS WILL RESULT IN COST SAVINGS ESTIMATED BETWEEN

$250 AND $300 MILLION

REDUCE INDIRECT STAFFING ($54M)

IMPROVE DIRECT LABOR PRODUCTIVITY ($31M)

REDUCE INVENTORY INVESTMENT ($19M)

REDUCE ENGINEERING SERVICES ($80-100M)

ESTABLISH THREE YEAR IMPROVEMENT PROGRAM ($100-120M)

Figure 5

NAVSEA FIVE-YEAR CUMMULATIVE SAVINGS PLAN

FY 86	FY 87	FY 88	FY 89	FY 90
$60M	$150M	$210M	$270M	$300M

figure 6

ORDNANCE NIIP GOALS

- REDUCE INDIRECT STAFFING BY 20%
- REDUCE NON-LABOR OVERHEAD BY 10%
- IMPROVE DIRECT LABOR PRODUCTIVITY BY 15%
- REDUCE ENGINEERING SERVICES BY 12%
- REDUCE MATERIAL INVENTORIES BY 15%

Figure 7

ORDNANCE NIF CENTERS OF EXCELLENCE

WEAPONS STATIONS

RETAIL, AMMUNITION MANAGEMENT
(SHIPLOAD, IMA, LOGISTICS, ORDNANCE STORAGE)
ORDNANCE PACKAGING, HANDLING, STORAGE AND TRANSPORTABILITY

TECHNICAL CENTERS

GUN & GUN FIRE CONTROL SYSTEMS
MICROELECTRONIC TECHNOLOGY
ELECTROCHEMICAL POWER SYSTEMS
PYROTECHNICS
SMALL ARMS
ENERGETIC CHEMICALS
ANTISUBMARINE WARFARE WEAPONS
UNDERSEA WARFARE COUNTER MEASURES
DEPOT MAINTENANCE
TESTING AND REPAIR
PERFORMANCE ASSESSMENT

COMBAT SYSTEMS ENGINEERING CENTERS

SURFACE SHIP COMBAT SYSTEM ENGINEERING
UNDERWATER MINE ENGINEERING

Figure 8

VALIDATED SAVINGS AND GOALS
FY86 - FY90

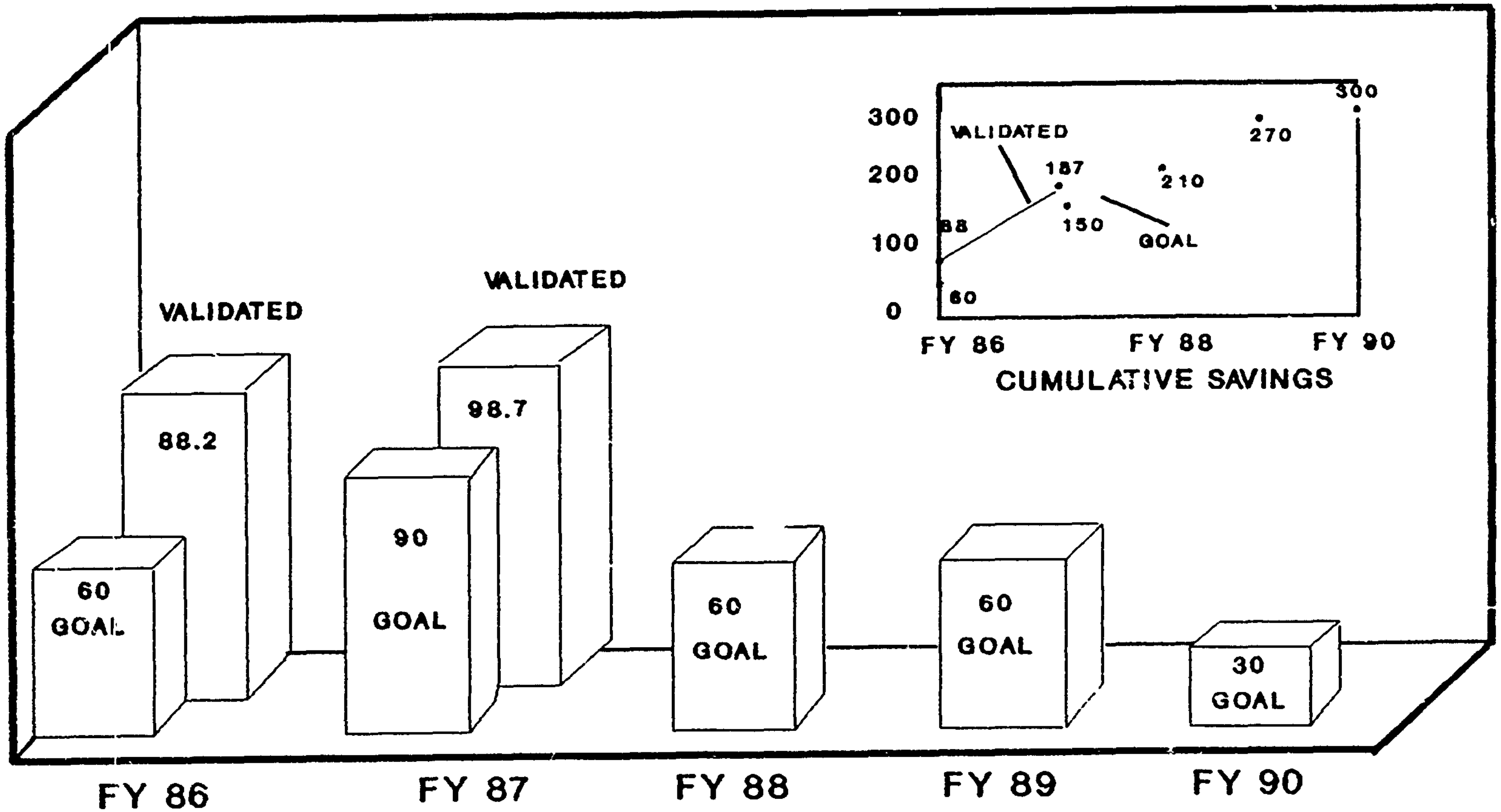
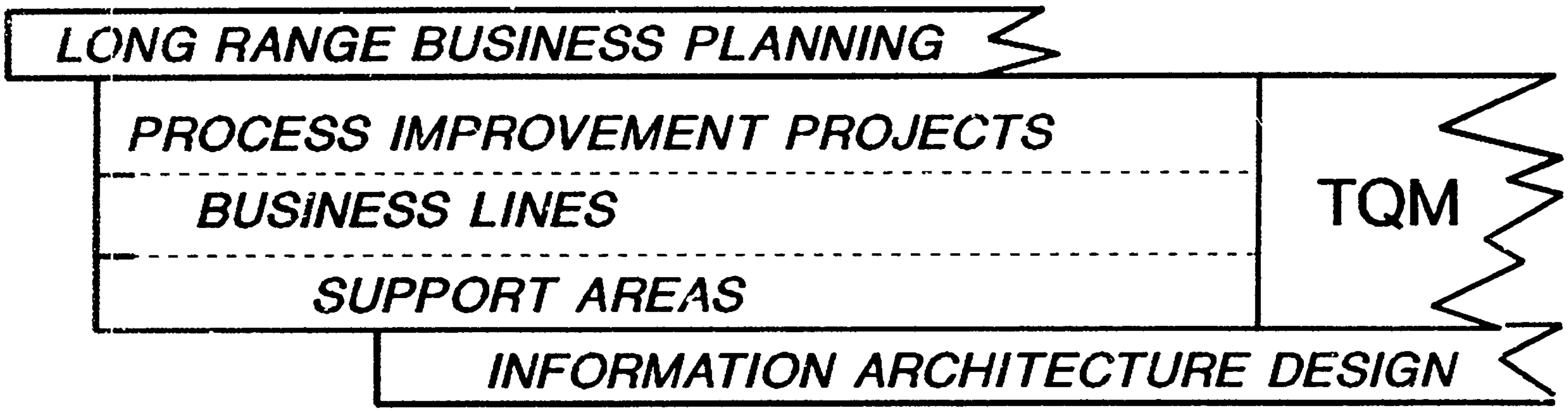


Figure 9

PROGRAM STRATEGY



<u>BUSINESS LINES</u>

PERFORMANCE INDICATOR MEASUREMENT SYSTEMS (PIMS)

* RSSI
* IMA
* DLM/MFG
* ENGINEERING

<u>SUPPORT AREAS</u>

PROCUREMENT
MATERIALS MANAGEMENT
PUBLIC WORKS

Figure 10

NIIP INITIATIVES

AS OF MARCH 1990

LONG RANGE BUSINESS PLANNING

NWS Charleston
NWS Concord
NWS Earle
NOS Louisville

PROCESS IMPROVEMENT PROJECTS

PIMS	NWS Yorktown (PILOT)
- RSSI	NWS Earle (Rollout)
	NWS Charleston (Rollout)
	NWS Concord (Rollout)
- IMA (ALM/SMS)	NWS Seal Beach (PILOT)
- DLM/MFG	NUWES Keyport (PILOT)
- ENGINEERING	NSWSES Port Hueneme (PILOT)

Figure 11

NIIP INITIATIVES

AS OF MARCH 1990

PROCUREMENT

NWSC Crange (PILOT)
NOS Indian Head (Rollout)
NOS Louisville (Rollout)

MATERIALS MANAGEMENT

NWSC Crane (PILOT)

PUBLIC WORKS DEPARTMENT

NWS Charleston (PILOT)
NWS Earle (Rollout)
NOS Indian Head (Rollout)

INFORMATION ARCHITECTURE DESIGN

NWS Concord (PILOT)
NWSC Crane (PILOT)

Figure 11 (Cont'd)

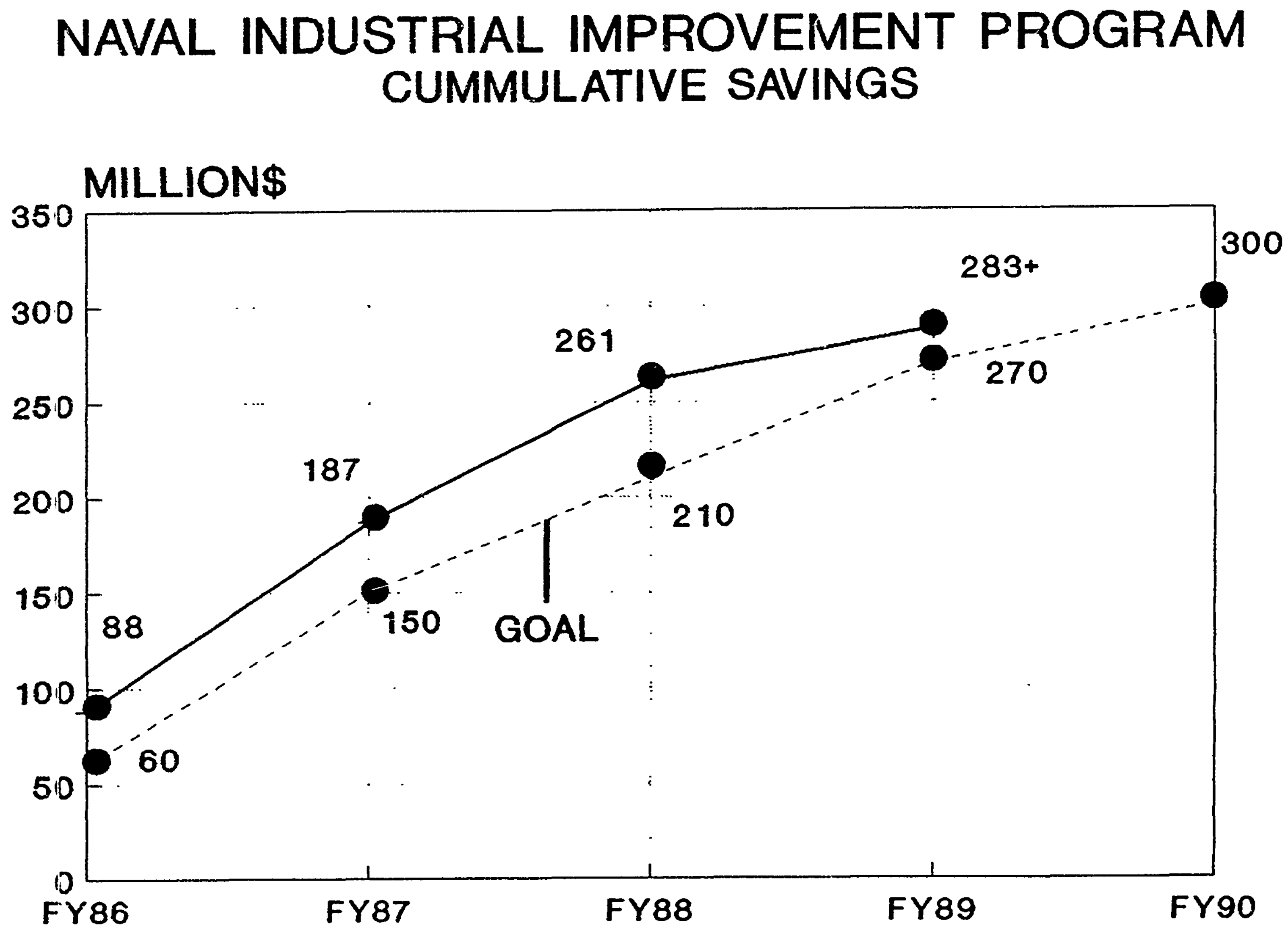

NAVAL INDUSTRIAL IMPROVEMENT PROGRAM
CUMMULATIVE SAVINGS
MILLION$
350
300
250
200
150
100
50
0
FY86
FY87
FY88
FY89
FY90
88
60
187
150
GOAL
261
210
283+
270
300

Figure 12

ORD-NIF WORKYEARS

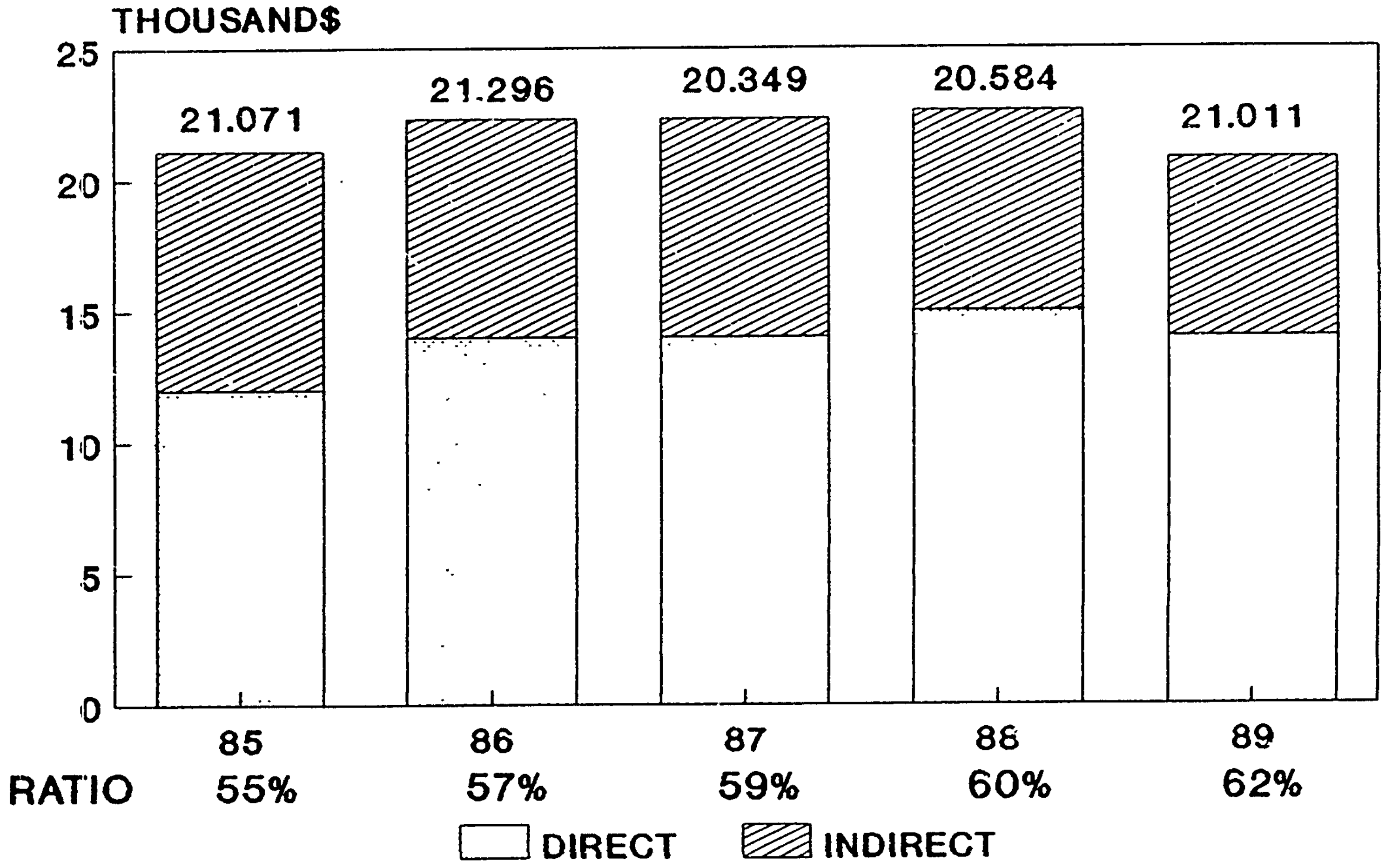


Figure 13

VISION FOR ORD-NIF

The ORD-NIF is looked to by both the public and private sector as a highly respected, well managed organization who is:

* technologically proficient in their assigned mission *
* comprised of a highly dedicated, talented and motivated workforce *
* operating a modern, smooth running capital facility *
* providing a safe and healthy work environment for employees and community *
* pleasure to do business with *

in short ...

* a good employer *
* a good customer *
* a good neighbor *
* a good supplier *
* a good custodian of taxpayer's money *

Figure 14

TOTAL QUALITY MANAGEMENT ITS PHILOSOPHY, BEGINNINGS AND PROCESS AND ITS APPLICATION TO F-14 DEPOT MAINTENANCE

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ABSTRACT

Since the mid-1970's, the Japanese productivity assault on the global markets has been extremely impressive. The primary objective of Japanese companies has been to increase market share and company growth. Profit has been a secondary objective as the Japanese strove to create and dominate the market, rather than merely to satisfy it. The principle reason for Japan's success has been their 40-year cultural commitment to quality, understanding the "voice of the customer", and the customer perception of the value of product quality. Through the contributions of Dr. W. Edwards Deming and others, U.S. industry has been driven to emulating the Japanese management philosophy by incorporating Total Quality Management (TQM).

Understanding the concepts of quality costs through the reduction of waste and process variation is fundamental to the TQM philosophy. The evolution in U.S. quality control demands a shift from the traditional method of auditing the finished product and improving quality by fixing problems to a method of auditing processes. Likewise, TQM demands proper use of statistical process control and continuous training of management and the work force to ensure continuous improvement and productivity.

This paper discusses how the Naval Aviation Depot (NADEP) Norfolk, Virginia, as an example of U.S. industry, employed the new management philosophy of TQM to reduce costs and boost productivity and efficiency. A specific application of TQM is highlighted with the preparation and implementation of the F-14 aircraft maintenance competition program. As part of this effort, the Norfolk depot's challenge was to streamline operations to minimize the cost of scheduled maintenance on a delivered F-14, while simultaneously maintaining quality. The competition against private industry for the aircraft workload provided unique apportunities to use TQM to make cultural changes throughout the depot. Norfolk would demonstrate that quality products are more a function of employee knowledge and interaction than the application of traditional quality control technology.

For the outstanding productivity gains achieved, the Norfolk depot won the 1988 U.S. Senate Productivity Award for Virginia. This award is the highest such honor bestowed to businesses in the state for performance. More importantly, the depot, along with its sister facility in North Island, California, won the F-14 competition on the basis of cost and technical capability. Norfolk performing as a quality company could not afford the old cliche "if you don't have enough time to do it right the first time, there's always enough time to do it over."

APPENDICES

LIST OF FIGURES

TABLES

SCENARIO

Total Quality Management and The State of Quality in the United States

The basic cause of American industry's loss in competitive position over the last 10-20 years has been the failure of top management to recognize that the world is in a new economic age. The United States' slow response in challenging outside competition, principally from Japan, has been indicative of the cultural differences existing between the U.S. and Japanese approach to quality. In many instances, U.S. top management has not known the true state of their companies until too late, taking an attitude of "if it's not broke, don't fix it." The U.S. attitude is centered around the traditional quality goal of "product conformance" to stated requirements (e.g., specification, customer needs, performance criteria, etc.)

The traditional method of product quality has been a barrier to U.S. companies in fully understanding the relationship between cost of rework and scrap to product quality - a principle long mastered by certain segments of Japanese industry operating in a global environment. American industry has focused on fixing problems by auditing the final product or by analyzing customer claims. An approach to quality assurance based strictly on inspection does not deal with process abnormalities and therefore guarantees two things: 1) management will always be in a reactionary mode, and 2) quality will never improve.

It has become obvious that if the U.S.. is to regain market share, it must adopt a new philosophy - one that is patterned after the Japanese view of product quality control where the "voice of the customer" is more important than the "voice of the engineer." The philosophy should promote an organizational capacity for improvement that leads to competitive advantage with results of increased quality, less rework, greater productivity and lower cost. It has been this commitment to eliminate waste ("Muda Nakusu") that has been the driver for quality activity in Japanese companies. Unfortunately, the "zero defects" program does not address the cost of quality and product optimization through dimensions employed by the Japanese. Further, the philosophy must include a system for educating and training all employees on a continuing basis to broaden the organization span-of-control (see Figure 1). This resource is probably the single most important factor contributing to Japanese successes in world markets. We must depart from the dominant form of quality activity that advocates auditing of finished goods by inspection and initiating corrective actions, i.e., managing by defects, which virtually truncates any efforts to identify sources of improvement to lower quality costs. U.S. supplier and production company management must audit the

process rather than the product to change system variation. Top management and executives should spend 80% of their time changing the system to improve process quality, and a maximum of 20% problem solving. With the latter, managers must properly use statistical process control (SPC) to identify causes of variability and separate common causes from special causes in process output. The Shewhart Cycle, developed by W.A. Shewhart, (see Figure 2) addresses "Plan-Do-Check-Act" as one of the baseline process improvement/SPC models for Total Quality Management (TQM).

TQM is a new management philosophy based on total commitment to constancy of improvement. It is derived from the Japanese near-obsession with quality and product excellence, embodied in their philosophy and operational aspects of Company-Wide Quality Control. TQM incorporates the management principles on quality and productivity improvement advocated by Dr. W. Edwards Deming, who is credited by the Japanese with fostering the movement that started their industrial phenomenon. The full set of Deming's principles are contained in fourteen points (see Table I).

With the Japanese defect or error rate at 500 to 1,000 times smaller than the U.S. in the 1982-83 timeframe, American management came to recognize that a TQM-like approach was desperately needed in this country to create quality companies. The term quality company refers to organizations that are distinguished by high quality in everything they do, where management recognizes that quality is not just isolated to the manufacturing process. With the elements of international competition increasing, the levels of performance of products must be continually raised to satisfy customer demands. Consumers are no longer going to accept defective workmanship and materials, unreliability, delays and unresponsiveness, especially as long as there are superior and cost-effective products or services available.

Establishing and implementing Dr. Deming's quality philosophy in the form of TQM initiatives will help ensure that organizations become or remain competitive and thereby survive. Figure 3 shows the five stages of TQM required for process improvement. While TQM is a diverse management strategy or psuedoblueprint for continuous improvement of all products and services, the philosophy is also based on being customer-oriented at all levels and areas of responsibilities. Successful program implementation and performance improvement throughout the work force demands executive leadership, vision and strong management commitment to prevent false starts or stagnation from occurring.

In the industrial sector many leaders have become preoccupied with the importance of making short-term profits and corporate mergers. In doing so, they have failed to focus on the critical element of customer satisfaction (i.e., "voice of the customer"). Satisfaction, not achieved by sales gimmicks, but by quality products as the fundamental basis for successful businesses. They failed to set in place a long-term vision for their companies, and to communicate that vision to the work force. They have treated quality as an added burden and an added cost, not understanding that high quality in every process is the key to lower costs and increased profitability.

By not tapping the available inherent abilities of workers to contribute to process improvement, management has inadvertently reinforced apathy and undesirable behavior in the workforce. To improve process efficiency and worker productivity and pride in workmanship, management must implement the technical and behavioral changes of the Deming philosophy (see Figure 4).

Under TQM, one of the most important factors in turning around a negative situation is to gain worker participation in reaching the company's business goals and objectives. Management must create a positive environment within the work force in order to achieve the teamwork and cooperation required for process improvement. To obtain desired employee behavior and job results, the cultural barriers within the workplace must be lowered to change individual and group attitudes. Top management's commitment to changing the environment is a fundamental requirement; endorsement of changes is not enough (see Appendix A for the Fourteen Obligations of Top Management). Interpersonal skills, participative management and employee initiatives should be stressed to achieve the target results. This can only be attained through a rigorous and continuous company-wide training program. Management must understand the philosophy; workers must understand the productivity and quality goals and be given the tools to do their jobs.

TQM organizations should be established with a formal and structured process-improvement methodology to provide the necessary top-to-bottom employee training, disciplined approaches, goal-setting objectives and project priorities. The TQM hierarchy within the company should flow down from an Executive Steering Committee (ESC) to Quality Management Boards (QMBs) at most supervisory levels, to Process

Action Teams (PATs) which investigate specific problems and provide feedback on recommendations and solutions. QMBs are permanent cross-functional teams made up of top and mid-level managers who are jointly responsible for a specific product or service. The structure of the boards should be such to improve com-

munication and cooperation by providing vertical and horizontal links throughout the organization. PATs are extenstions of the QMBs and gather and analyze data on specific areas or projects. Information processing at the QMB and PAT levels provides excellent opportunities for coordinated interchanges of ideas in the pursuit of one broad, unending objective: continuous improvement in quality and productivity. This interaction is the heart of the TQM system.

Once individual program objectives are established and initiatives activated with the desired changes in-place, performance trends and productivity gains should follow. A reward system, coupled with praise by management, can provide a solid stimulus for employee motivation to excel and continue desirable individual and group behavior. Popular incentives in the form of gain sharing plans (also known as profit sharing) can be introduced as positive reinforcement for work force performance.

Creating a quality transformation within a company is a lengthy process, requiring dedicated involvement, comprehensive training, some hardships and a great deal of patience. It took the Ford Motor Company nearly six years to fully absorb and implement the philosophies of Dr. Deming and the applications of SPC. Ford's program was complemented by consultants, Dr. Kaoru Ishikawa, a foremost quality control/SPC expert, and Dr. Genichi Taguchi, a highly-acclaimed statistician. Taguchi's concepts of the cost of quality and design of experiments go well beyond the SPC approach, and have been acknowledged as being crucial to the success at Ford.

Taguchi's methods have implications industry-wide and are key ingredients to competitive position. His cost vs. quality principles are listed as follows:

- Cost is the most important feature of any product.
- Cost cannot be reduced without affecting quality.
- Quality can be improved without increasing cost.
- Cost can be reduced by improving quality.

TQM at U.S. Naval Aviation Depots

Naval Aviation Depots (NADEPs) are unique military industrial complexes, designed to provide scheduled maintenance, engineering, manufacturing and logistics support of aircraft, engines, components and special test equipment. There are six such depots in the U.S. They are located in: Alameda and North Island, California; Jacksonville and Pensacola, Florida; Norfolk, Virginia; and Cherry Point, North Carolina. The depots operate as semi-autonomous field activities within the corporate structure of the Naval Air Systems Command (NAVAIR), with Cherry Point the only Marine Corps facility. The mix of aviation products and services is significantly different at each site, and personnel levels are individually adjusted, based on quarterly/annual workload projections. Manpower levels at each depot range from approximately 3100 to 4800 employees, the lowest levels in recent memory.

The depots are financed from Navy Industrial Fund (NIF) appropriations, a monetary system designed to break-even each year (i.e. zero profit or loss). Working capital is provided by the NIF treasury for actual depot expenditures incurred, and restored on a reimbursable cost basis when customers are billed for work performed. Product and service costs are computed from stabilized NIF rates, called "Norms", which have been established two years in advance of a planned fiscal year (FY). With annual budget executions of about $2 billion dollars, the NADEP corporation would rank well in the Fortune 500.

All of the NADEPs have pride and commitment in their mission of "service to the fleet", for they are the support backbone of naval aviation readiness. As part of their mission tasks, they provide standard, emergency and special repairs, overhauls and modifications, engineering investigations, fabrication/plating, and a myriad of other production and operational support functions and services. By maintaining all of the diversified capabilities, including the material and tools necessary to perform any aircraft structural repair or component process, the depots in some respect resemble large sophisticated job shops. Their "can do" attitude is reflected in the fact that artisans and engineers are often tasked on short notice to evaluate and resolve critical problems at remote sites or on board aircraft carriers. Depot field teams and accident investigation teams can be expected to travel and work weekends and holidays to minimize operational impacts.

While the depots have maintained very good reputations for quality work and rapid response to contingencies, they have not been generally known for low cost, highly productive operations. Taking aim at this fact and to be in compliance with the President's target of 4% annual productivity improvement, the Department of Defense (DoD) implemented the concept of Total Quality Management (TQM) in 1986. This action followed observations and feedback received from the private sector, after the concept had taken hold in a number of major companies. From the Navy's perspective, the depots were expected to use TQM as a primary means to reduce costs, eliminate inefficiencies and enhance their competitive positions. Depot nomenclature was changed to

more accurately reflect their mission and promote a new image and corporate direction. Formerly known as Naval Air Rework Facilities, or NARFs, in 1987 the NARFs became Naval Aviation Depots as part of the TQM process, removing "rework" from their titles, as some felt this word implied recognition and acceptance of defects. In translating Deming's fourteen points, to depot activities, they were to reassess the way they manage resources, particularly the workforce, focus on customer requirements and utilize statistical process control (SPC) techniques and control charts as tools to improve process quality. Specific skills had to be developed or acquired to understand and apply SPC to identify abnormal process variations and the sources of improvement. A new area of management philosophy had begun in the NADEP corporation.

During the early phases of TQM implementation, NAVAIR guidance on how to apply the new way of doing business was inadequate, thereby creating some initial program false starts. In-depth knowledge of statistical methods to identify problem areas and document or substantiate progress made was lacking at all levels. However, the corporate direction given was simple: conform and show cost savings as soon as practical. Each depot was left up to its own devices and means in developing TQM implementation plans and in-house training for their respective facilities. Consultants and facilitators were contracted to assist in the integration of TQM. Strategic planning was initiated to promote the concept of being national assets for Naval Aviation and to establish business plan goals, projections and priorities. The TQM organization hierarchy is depicted in Figure 5.

NAVAIR and its depot analysis center preached that all NADEPs should band together to form a more harmonious and effective corporation. At the same time, however, they continued the old way of dealing with available quarterly workload, which tended to encourage "cut-throat" competition and disharmony. Distribution of quarterly workload had been based on a subjective fair-share arrangement in an effort to balance direct manhours to personnel endstrengths and maximize productive ratios. This bias of treating manpower as a fixed variable and varying workload, however, offered little incentive or reward for depots to minimize people and improve efficiency. Each quarter a comparison of depot past performance was made from inaccurate evaluation criteria which skewed data and distorted final rankings. Summarized results were published in the Management Effectiveness Performance Evaluation (MEPE) Report. The MEPE was controversial, often angering those who felt unjustly penalized, or felt that others had benefitted by manipulating numbers. In essence, the system inadvertently created a dysfunctional relationship that focused on improving the numbers rather than the actual improvement itself. These quality objectives tended to contribute more towards a "numbers game" for management in evaluating performance. Finally, the MEPE Report was canceled when it was recognized as being counterproductive to TQM objectives.

As part of the Naval Industrial Improvement Program, the Navy accelerated the TQM productivity initiatives already underway by directing that a cumulative $1 billion dollars be cut from the NADEP FY87-91 Operating Budget. TQM would be employed to meet the cost reduction challenge and exceed the imposed mandatory annual cost targets. NADEP Norfolk led the corporation in cost savings, accomplishing this feat in spite of a major industrial accident in April 1986, involving 350,000 sq. ft. of floor space. An on-site transformer fire contaminated two adjacent buildings with toxic PCBs and dioxins, causing permanent closure and programmed demolition in 1990. The buildings housed many of the A-6 and F-14 aircraft critical assembly processes, including wing/tail, landing gear, hydraulic components, brakes, canopies, radomes and engine kits. Hundreds of workers were displaced, process and product lines had to be relocated, shortages managed and schedules reestablished. Over $180 million dollars in parts and equipment were salvaged through a freon wash decontamination process, while 300 tractor-trailer truckloads went to a toxic waste dump. The extraordinary effort by the work force to overcome this crisis emulated the central theme of TQM.

After three and a half years of TQM, steady progress had been made at the depots, as resistance to change eroded and general acceptance became widespread. Initially, many depot employees, including top management, were skeptical of TQM, for other productivity initiatives had previously come and gone. Since program longevity is often directly related to the degree of high-level visibility, and the duration of that support, many adopted a wait-and-see posture. However, those with power who balked at making massive changes or impeded progress, were known a "dinosaurs", and were pushed aside or opted to retire. It soon became clear that the Navy was adamant about cutting the depot "fat", a situation that was compounded by forecasts of declining workload. Competition for decreasing available resources within the depot corporation would become extremely intense; the destinies of all facilities would be adversely affected, unless the proper adjustments were made. TQM appeared to be the right adjustment vehicle for meeting the seemingly opposite demands of better efficiency vs. a downward workload spiral. Therefore, it was in each depot's best interests to recognize the true benefits of TQM and evolve into true quality companies. For NADEPs Norfolk and North Island, this fact would become particularly acute, as they later transformed

their F-14 aircraft programs into cost-effective centers of excellence.

PROBLEM

Introduction of Competition

In early FY87, the Navy offered another challenge - competition with the private sector for the F-14 aircraft Standard Depot Level Maintenance (SDLM) workload. The competition would spearhead a new view of productivity at NADEPs Norfolk and North Island, the only depots which worked the F-14 aircraft, but ultimately it would influence the treatment of cost relationships at all depots. This challenge was perhaps the most serious threat ever experienced by either depot, as future F-14 workload was to be determined on the basis of competition against the aerospace industry. Contract award would be made based on cost as the primary driver, while technical adequacy would play a much smaller role in the selection. Since a depot's strength was technical capability and expertise, but not cost, a survivability problem was potentially at hand. At least 700 depot jobs were at stake in the outcome, as reduction-in-force actions at both sites would be required if the F-14 business was lost. In general, people had to perceive that the reward or payoff in TQM was worth the effort. Continued employment was certainly one of the strongest motivators. As was the case at Norfolk with the PCB crisis, the F-14 competition created a ripple effect of concern throughout the work force, causing groups to band together to get the job done and leadership to emerge. A TQM transformation of doing more with less, while maintaining product quality and customer satisfaction, was required to reach the target levels of efficiency and productivity.

In preparing the joint proposal for F-14 competition, success depended on teamwork and cooperation between both facilities, and whether they were willing to accept the pain of undertaking the high degree of restructuring necessary to attain parity in competitive position. Norfolk and North Island had to start from scratch, as there was no resident experience in competing workload and no team was in place. Not only did the F-14 program have to be revamped, but the accounting system had to be changed to support reporting requirements of the realigned cost centers. Norfolk, as the Navy's primary engineering activity for the F-14 (and A-6), took the lead in the joint proposal effort to establish cost reduction strategies. The submitted proposal's bottom-line reflected the average cost of a delivered aircraft, consisting of the estimated work content (manhours) multiplied by the F-14 burdened labor rate, plus direct material.

The actions summarized in this section took place at NADEP Norfolk and are typical of similar events conducted at NADEP North Island. In parallel with the proposal team effort, Norfolk assembled a cadre of experts to specifically address minimizing costs associated with direct labor, production overhead, and General and Administrative (G & A). The primary areas of interest were the F-14 aircraft line organization itself, aircraft work content, cost center subcomponents and their contributions to the F-14 and other programs, manpower and allocated costs (G & A). A review of depot maintenance specifications and the Request For Proposal (RFP) enabled the elimination of unnecessary disassembly work, scrubbing of other tasks, and separation of the aircraft work package into two cost categories: "basic" and "over and above". The first term refers to all tasks that were required by the standard depot level maintenance specification itself, and the second includes all additional work performed. As commonly occurred in the private sector, the "over and aboves" were bid at higher labor rates, and unfunded work was no longer accepted. If the depots were expected to improve cost performance and become more competitive with industry, then the playing field had to be leveled by consideration of the adoption of costing techniques used by defense contractors.

The F-14 program was streamlined by trial and error as a prototype line organization, reducing people, modifying and consolidating the process flow on the floor and performing a bottom-up labor rate review of cost centers. Management of indirect support to direct cost centers was changed from a "push" to a "pull" philosophy. This method allowed the direct cost center managers to negotiate the desired amounts of indirect support required (i.e. "pull"). This change gave cost center managers more control over their domains, making them more accountable for labor expenditures, and improving the visibility of indirect cost distribution. Cost centers were redefined in an effort to minimize F-14 program costs and more efficiently spread all costs across the facility. The restructure expanded the number of cost centers, which contributed to the F-14 program rate, from four cumbersome divisions to ten streamlined organizations (see Figures 6 and 7). To minimize the direct labor charged to a product, excess workers were temporarily transferred to a Command Work Center as indirect, and performed a multitude of facility support tasks. This productivity initiative helped to lower product costs by increasing efficiency and minimizing the idle or unproductive members of the work force.

NADEP Norfolk's TQM approach on F-14 competition covered all aspects of the program, including a thorough investigation of factors contributing to cost center performance, to identify the sources of improvement within and outside the depot. As a by-product of the F-14 reor-

ganization and cost center strategies, there were innovative cost reduction accomplishments in the areas of direct labor, production overhead and G & A, which formed the nucleus for the effort. For direct labor, focus was placed on the journeyman, or artisan level, as the criteria for process flow analyses and the work standards were removed from the floor; a more optimal mix of skills was obtained by cross-training workers without impacting quality; the second ("B") shift was significantly reduced and the third ("C") shift was deleted except for isolated functions; and F-14 overtime was virtually eliminated. In production overhead, one level of supervision was eliminated (the positions of General Foreman); first line supervisors (Foremen) were converted to direct labor; aircraft indirect material from the "hardware stores" and centralized kitting (direct) were reduced to minimize waste; service group support was reduced as a result of the negotiation process with cost center managers; and certain indirect personnel were reassigned to cost centers as direct functions (engineering, quality assurance, planning & estimating, and production control). G & A was allocated on a total cost vs. manhour basis; contract and service group expenses (e.g. computer time, facility maintenance, etc.) were reduced.

As a result of the sweeping changes, cost center managers became more educated, better trained and more aware of cost accountability, process functional relationships and work force contributions to facility productivity, quality and cost trends. Inefficient operations were no longer subsidized or hidden from view, and every cost center rate fell, ensuring that cost growth did not occur in any other area as a fallout from minimizing F-14 costs (see Figure 8). The net outcome of this TQM project was increased productivity in terms of a lower price and reduced aircraft turn-around-time, with less manhour/material expenditures. Quality control was considered paramount; cutting corners to save money and time was not tolerated to avoid quality or safety impacts. Norfolk was sensitive to any perceived decline in quality, for any major oversights would invoke customer dissatisfaction and demands to immediately fix the deficiencies. These problems would have increased costs in the long run and could have led to a poor reputation and loss of future business at the depot. Block diagrams representing conceptions of traditional methods product quality at the depot are depicted in Figures 9 and 10.

In a competitive environment with less resources, it was the emphasis in meeting customer essential requirements through the elimination of major discrepancies on delivered products, that constituted a radical change in the concept of product quality. A revised approach to product quality as advocated by Deming was applied to the F-14 program (see Figure 11). This TQM approach by Norfolk employed the philosophy long advocated by the Japanese, whereby quality and cost are considered as inverse relationships, atypical for U.S. industry. Improving quality is more cost effective than the cost of rework and scrap, which are really quality costs, and the result of not doing the job right the first time. The transformation of building quality into the product is a commitment to continuous improvement. To do otherwise, is tantamount to managing by defects, with reliance on mass inspection procedures and problem-solving actions to maintain quality.

In July, 1988, NADEPS Norfolk and North Island were successful in winning the F-14 competition against the bidding aerospace companies (see Table II). This event became a productivity benchmark within the depot corporation, signifying that TQM was an inseparable tool in achieving and maintaining competitive position. However, while Norfolk was successful in winning the competition, it has been a long uphill struggle to implement changes through TQM actions. The conflicts involved as a result of disbanding existing "rice bowls" or power bases to achieve reorganizational goals and the shifting from a traditional quality assurance approach was particularly intense at times.

One year later, Norfolk delivered it's first "competition" F-14, which was subsequently accepted by the Navy as a zero-defect aircraft. This aircraft was sold at a unit savings of approximately 30% over the previous average cost of F-14 standard depot level maintenance, and attained without loss in product quality. Providing F-14 aircraft inductions remain in economic quantities, the forecasted production costs are expected to continue to decrease as the learning curve and follow-on process improvements take shape. What Deming and others have preached on productivity, quality and cost had, in fact, correctly determined competitive position and business survivability.

MODEL

Guidelines for TQM Implementation

The TQM approach emphasizes the major role that managers have in achieving quality and productivity improvement in an organization. Dr. Deming and other TQM proponents estimate that up to 85% of quality improvement is under direct control of management and cannot be remedied by the hourly worker or staff member. In fact, TQM stresses the point that without management commitment, it cannot succeed.

One aid to management in fulfilling their responsibilities in implementing TQM is the seven step model for continuous improvement (see Figure 12). In Step

One, Establish the Management and Cultural Environment, TQM requires management to exercise leadership to allow conditions for the process to flourish. Management must create the environment for change. It must accept the initial learning curve investment and the necessary gestation period for the new systems to become productive.

Step Two, Defining the Mission, discusses the fact that everyone has a customer (internal and external), and TQM concentrates on providing customers with products that consistently meet their needs. Everyone in the organization must know the purpose of his or her job and how their job relates to others in the organization. Steps that can be taken to define an organizations' mission can be seen in Table III.

Step Three is to Set Performance Improvement Goals. These goals must reflect an understanding of the process capabilities of the organization so that realistic goals can be set. They should first be set at the senior management level, and should reflect strategic choices about the critical processes and customer desires in which success is essential to organization survival. Middle and line management set both functional and process improvement goals to achieve the strategic goals set by top management. In some organizations, top management comprises the Executive Steering Committee. They establish Quality Management Boards who in turn establish ad hoc Process Action Teams, both of whom interface with shop level TQM actions. Thus, the entire organization is effectively interlinked to form an ideal performance improvement setting.

Step Four, Establish Improvement Projects and Action Plans, flows the goals developed in Step Three from the executive level to operations. Figure 13 shows how the activities of the groups and teams established in Step One coordinate to implement these goals. Notice how the functions of Senior Management are cross-functional and are geared toward allowing the process to occur and to provide necessary resources, while those of the Improvement and Problem-Solving teams are more directed towards the actual problem studies, analysis and improvements.

Step Five is to Implement Projects with Performance Tools and Methodologies. This requires first defining the process, then identifying customer and supplier requirements, i.e. knowing what is required of the process, the role of process members, what is available from suppliers, and what is required by customers. Secondly, measures need to be developed. A goal that cannot be measured in some fashion is not appropriate for the process improvement model. Thirdly, conformance to customer needs must be assessed, improvement opportunities analyzed, possibly through fishbone diagrams, identification and ranking of improvement opportunities must be accomplished (through Pareto charts), and lastly, the process quality must be improved by reducing the magnitude and range of variation. See Figure 14.

Step Six is Evaluation. Measurement, evaluation and reporting are essential elements of the continuous improvement process. They focus on the effectiveness of improvement efforts and identify areas for future improvement. All levels of management are involved in this process.

Step Seven is Review and Recycle. Most human efforts go through the phases of Beginning-Growth-Fade-out. Under TQM, it is necessary to perpetuate the continuous improvement process forever. Historically, approaches to improving efficiency tend to have a limited survival cycle and, if left unattended, will become stagnate and performance will decline. Quality circles in U.S. industry are an example of shop or "grass roots" efforts to improve processes and local quality-of-life. But because there has been minimal management involvement, the circles have been only marginally effective and many have disbanded or become inactive as new ones formed.

All employees will need to review progress with respect to improvement efforts and modify or rejuvenate existing approaches for the next progression of methods. Quality circles may evolve into autonomous work teams. Suggestion awards may evolve into gainsharing. SPC may evolve into variability reduction. This constant evolution reinforces the idea that TQM is not a program but a new philosophy for day-to-day behavior for each member of the organization.

SOLUTION TO THE MODEL

Tools and Techniques

Deming's principle #10 states, "Eliminate slogans and targets asking for increased productivity without providing methods." In keeping with this philosophy, we explored the TQM concept in terms of the process improvement model and how TQM could be applied in a production environment using statistical process control (SPC) methods.

The most frequently cited process improvement approach is the aforementioned Shewhart Cycle, a subset of the seven step Total Quality Management Model, and developed by W.A. Shewhart, a colleague of Deming. The cycle consists of four basic phases—plan, do, check, and act—which repeat indefinitely (see Figure 15). First, management identifies organizational goals for

quality improvement in the Plan phase. Next, they identify, collect, and analyze process variables in the Do/Check phases. Then, they evaluate and improve the process in the Act phase. The cycle continues.

In the Navy depot, as previously mentioned, the quality improvement team consists of the Executive Steering Committee (ESC), Quality Management Boards (QMBs) and Process Action Teams (PATs), (refer to Figure 5). The Shewhart Cycle is appropriately applied at every level for process improvement. Adapting the Deming philosophy and TQM organizational structure, the SPC emphasis comes from the top and filters down to the lower levels, with process feedback provided as required.

As demonstrated with F-14 competition, survival in the marketplace is the pre-requisite for success. Quality improvement can be translated to a monetary value or, in other words, the bottom line is the delivered unit cost to the customer. As Jack Katzen, Assistant Secretary of Defense, pointed out, the Japanese did not start out with quality as their primary objective-it was the element of cost.

Determining how to continually manufacture high quality products at the lowest possible costs to gain international competitive advantage correlates with the Japanese strategy of emphasizing market share over profits. Quality improvement in production processes can and will lead to cost reduction as stressed by Deming and Taguchi. Once the quality goals are quantified, and training provided on the tools/techniques involved, strong incentives exist for process improvements.

In this regard, we need to look at how the products/services can be provided consistently and economically? One way is to reduce the variability in production processes. Variation is what allows results to deviate from the target quality level. Some examples of variations which impact production costs may be material defects, over/under adjustments on machines, production schedule delays, or excess inventory. To reduce variation, statistics can be used to measure and track quality parameters in the process control, thus the term Statistical Process Control (SPC).

There are, however, several pitfalls to the use of SPC—the most common and serious being that SPC is a technique or method to control process improvement. There is always a danger that SPC will be misused by production operators who feel that as long as the process outputs are within the established control limits, everything is fine (i.e., perfect quality). Likewise, if a process is not stable, any attempt to use statistical techniques such as analysis of variance would be futile and produce misleading information. For instance, data sampling on a downward trend of part elongations by order of manufacture, would show a normal distribution (perhaps even symmetrical); but the downward trend would probably mean that either something was wrong with the manufacturing process, or with the measuring/ calibration instrument.

The SPC tools shown in Figure 16 may appear simple, but their utility to management is actually very useful. Examples from the Navy depot Process Action Team will illustrate the point.

A. Flow Chart - This is a step by step illustration that identifies the actual or ideal path of a process and any deviation (see Figure 17). It's always a good idea to make sure everyone agrees on what is being examined.

B. Pareto Diagram - The Pareto Diagram is a vertical bar graph that compares the relative importance of problems, events, or successes (see Figure 18). This helps to focus on the biggest problem areas, thus the Pareto Principle.

C. Fishbone Diagram - Sometimes called a Cause and Effect diagram (see Figure 19), the Fishbone Diagram is used by groups (usually at the PAT or QMB levels) in brainstorming sessions to identify, explore, and display all possible causes leading to a specific problem or condition. It takes a complex process with multiple interactions and breaks it down to different manageable parts for follow-on analyses.

D. Histogram - A Histogram takes measurement data and displays its distribution (see Figure 20). It reveals the amount of variation within any process has within it.

E. Scatter Plot - A Scatter Plot Diagram displays what happens to one variable when another one changes (see Figure 21). It does not prove that one variable causes the other, but it does show whether a relationship/correlation exists and the strength of that relationship as illustrated by Figure 22. It is possible that x and y could be related negatively, positively, or not at all.

F. Control Chart - A run chart is the simplest way of showing trends over time (see Figure 23) while the control chart is a run chart with statistically determined upper and lower bounds for process control (see Figure 24). Using defects as an example, upper and lower bounds represent what is unacceptable and what is realistically achievable. If points fall outside of the limits or show unnatural patterns, they are said to be "out of control." Two types of causes that may lead to processes being "out of control" or not stable are common and special. This corresponds to the Do and Check phases of the Shewhart Cycle where the power of a control chart is to identify the causes of variability and separate the com-

mon causes from the special causes. Common causes are variations between the limits. They are factors within the system or faults of the system (e.g., manpower, material, machine, method, or environment) which remain until corrected or reduced. Special causes are indicated by points falling outside of the control limits and they usually are the result of variation not common to all of the lots or to all the areas involved.

Elimination/reduction of common causes can only be effected by action from management. Therefore, treatment of common causes is the responsibility of management as a function of constant process improvement. Special causes, on the other hand, will come and go and return unless eliminated. Their discovery and removal are usually the responsibility of someone who is directly connected with the operation or a related operation.

Figure 25 summarizes how Statistical Process Control fits into TQM. Flow charts are used to display the process; Pareto Diagrams are used to identify major problems; Fishbone Diagrams provide a means for brainstorming problem solving; Histograms present past records of measured data; Scatter Plot Diagrams are used to identify casual relationships; and Control Charts are used to monitor and track the process.

As control charts are the backbone for SPC methodologies for TQM, there is a need to guard against improper usage. The Shewhart rule for a process initially in control is to have 2/3 of the points within 1/3 of the limits and some points outside the limits. Any process can be made to look in control due to sampling techniques used. The idea is to try different sampling schemes to achieve the Shewhart result stated above. Once obtained, the next step is to change the process until all points fall within the limits (reduce variation). Then, resample to again show some projects out of limits, and repeat as an iterative process until the control limits are eventually narrowed to values that reflect a totally stable process.

Improper utilization of SPC methods, combined with the lack of knowledge of product/process design optimization, are the biggest inhibitors to process improvement. Under the Deming philosophy, these barriers can be lowered through continual education and training from top management on down. In order to achieve long-term success in quality and cost improvements, TQM in the depots must include heavy applications of the SPC tools/techniques available and expand into the Taguchi methods of quality.

RECOMMENDED SOLUTION TO THE PROBLEM

The depots were initially ill-prepared for F-14 competition and struggled through the evolution of events to reach their cost-reduction objectives. NADEP Norfolk also went through a "baptism under fire" to establish and implement a successful TQM movement in the facility. What would have happened if no one had ever heard of TQM? Most individuals might say that changes would still have occurred, but they would have been more difficult to achieve. Others might offer that the magnitude and extent of the changes would not have been possible. In this regard, changing people's paradigms and breaching the intrinsic cultural barriers is a lengthy process which often has mixed results. Unless there is a structure and discipline in place to recognize, enforce and pursue process improvement, productivity initiatives will falter and become unraveled. It is virtually impossible to maintain continuous improvement and avoid performance decline without a philosophy such as TQM and top management commitment to change. TQM provides the central focus for constancy of improvement and the foundation for management and workforce to seek unified common organizational goals.

So if TQM is so great, what recommendations could be made for the depots? Our first recommendation is to utilize the seven step management model as a training aid for integrating the TQM philosophy into the depot. The model could also be used by top management during the initial phase of business strategy determination if it was modified to include this function. Top management needs the availability of tools and techniques to assist in the initial decision-making process (the "Plan" cycle shown in Figure 2) in order to reduce uncertainty. Hence, our second recommendation is to include strategic planning actions under Step One to support new business opportunities or change major processes in production operations. We believe that employment of programs such as PERT (Program Evaluation Review Technique) can be of significant value in understanding the flow sensitivities of new processes and minimize trial and error efforts. In Appendix B we have included the F-14 process and critical path analysis which could be used in modeling F-14 and A-6 aircraft competition or other similar programs. New products which exhibit diverse processes could be modeled accordingly and provide useful analytical information to top management prior to issuing direction to the Business Office.

Our third TQM recommendation is to incorporate Dr. Genichi Taguchi's cost vs. quality principles and his statistical methods into the TQM base-line for depots. It is interesting to note that TQM guidelines as structured by DoD and the Navy do not stress Taguchi's cost versus quality principles, nor his methods to improve quality. Extensive programs could be made in reducing process variation, thereby lowering cost and increasing quality. To date, this is virtually an untapped area of

process improvement in the NADEP corporation. If properly applied, the Taguchi methods will demonstrate the additional quality costs involved and expressed in the form of Quality Loss Functions which are based on material and process specification variability for suppliers, vendors and in-house operations. Each source of quality input can be empirically calculated and its contribution relationship to product quality explicitly demonstrated (see Appendix C for supplemental information on the Quality Loss Function). This approach is an ideal mechanism for providing feedback on any stage or process in the production operations cycle. Through quality loss functions, top and middle management can optimize many fabrication, manufacturing/assembly, supply and transportation processes. The inclusion of these methods will enhance the under-standing of specific quality costs and their effects on process improvement and depot productivity. If the concepts are implemented, the depots will be exposed to the techniques employed in design of experiments for process control.

Our fourth recommendation deals with the concept of quality transformation. While the depots have incorporated the general guidelines (shown in Table IV) for carrying out the transformation required to depart from the traditional product quality approach, the associated strategies have only been partially adopted. This oversight is primarily due to a lack of understanding on how to apply the guidelines. Shown in Table V are six strategies considered germane to effectively beginning the process of achieving a quality transformation. As depicted in Figure 11, Deming's conceptual picture of product quality is continuous improvement based on process audit, with multiple feedback loops and is oriented towards customer satisfaction. This concept is not total unless both parts of the quality transformation take place within the organization.

In conclusion, we believe that the third and fourth recommendations are interrelated. Management must plan on addressing both areas in order to achieve significant and repetitive improvement in product quality. The most important element in production is cost. Cost optimization can only be attained if the quality aspects are properly accounted for and maintained within the system. The lowest cost and highest quality mix is the future yardstick of performance of quality assurance and control in the depots.

APPENDIX A

Fourteen Obligations of Top Management

Dr. Deming has tailored his fourteen management principles for executive/senior management applications. These were summarized by the Product Quality Office, Manufacturing Staff, and Ford Motor Company as follows:

1. Innovate and allocate resources to fulfill the long-range needs of the company and customerrather than short-term profitability.

2. Discard the old philosophy of accepting defective products.

3. Eliminate dependence on mass inspection for quality control; instead, depend on process control through statistical techniques.

4. Reduce the number of multiple source suppliers. Price has no meaning without an integral consideration for quality. Encourage suppliers to use statistical process control.

5. Use statistical techniques to identify the two sources of waste - system (85%) and local faults (15%); strive to constantly reduce this waste.

6. Institute more thorough, better job-related training.

7. Provide supervision with knowledge of statistical methods; encourage use of these methods to identify which defects should be investigated for solution.

8. Reduce fear throughout the organization by encouraging open, two-way, non-punitive communication. The economic loss resulting from fear to ask questions or report trouble is appalling.

9. Help reduce waste by encouraging design, research and sales people to learn more about the problems of production.

10. Eliminate the use of goals and slogans to encourage productivity, unless training and management support is also provided.

11. Closely examine the impact of work standards. Do they consider quality or help anyone do a better job? They often act as an impediment to productivity improvement.

12. Institute rudimentary statistical training on a broad scale.

13. Institute a vigorous program for retraining people in new skills, to keep up with changes in materials, methods, product design, and machinery.

14. Make maximum use of statistical knowledge and talent in your company.

APPENDIX B

PERT Analysis

In keeping with the goal of constancy for improvement, we examined the Depot's approach to the F-14 competition for possible improvement. We found that by applying PERT at the Depot Executive Board level, a more scientific strategy may be implemented to establish a competitive bidding position than the trial and error method that was actually used.

Before the Executive Order of 1986, depot executives were not TQM trained. It was business as usual for many and no attempt was made to change the way operations were performed. It wasn't until the $1 billion dollar cut in the Depot's FY 1987-91 budget that the F-14 competition became the "sink or swim" focus of gearing up for TQM implementation and, at the same time, competition in proposal preparation.

The Executive Steering Committee at the Depot is responsible for providing top-down guidance and setting organizational goals to implement TQM within the F-14 competition. The success in achieving a competitive position relies largely on the Committee's strategic planning in this early stage. After analyzing the overall process of aircraft overhauls, we determined that the cost and schedule determination processes in this phase of the F-14 competition could be improved through the use of PERT/CPM. PERT was developed by the Navy Special Projects Office, and CPM (Critical Path Method) by Du Pont, Remington, Rand Univac, and Mauchly Associates.

The Depot has always been technically capable of doing the work; but to instill better quality, thus reducing cost and becoming more competitive, a focus on better allocation of resources and less waste is the basis for process improvement.

A project is composed of sub-tasks or sub-processes at various levels. The relationship between different processes dictates the sequence of work flow. Since each process occupies a certain portion of the resources, any variation in it will impact the project as a whole, particularly if it is on the critical path. By focusing on reducing the variabilities in each of the sub-processes, the quality improvement team will be working towards specific measurable goals using statistical process control with definite direction. Further, the time and dollar constraints on any project will give strong incentives to streamline the process flow and to minimize any variation in the sub-processes. For the F-14 competition, the Depot PATs had to revamp the F-14 overhaul process in order to minimize cost and to achieve a competitive bidding position against their private counterparts. This proposal preparation stage serves as an opportunity for TQM strategic planning.

Since the project is comprised of activities, the total quality of the project is dependent on the quality of each activity which is delegated to the lower level QMBs. If, for instance, minimizing defects is the goal, the variance at each activity should be targeted to zero defect. This top-down approach links the executive board with QMBs and PATs at branch or shop levels. By constantly monitoring the progress throughout the project, any deviation attributed to special causes may be handled by the executive board and routine causes by the QMB or PAT. The probability of producing a quality product or service is no longer left to chance but to the players involved.

For the F-14 competition, the overhaul process is broken down to 18 activities. Figure B1 and Table B1 illustrate these, their relationships, and the associated time durations. The optimistic, most likely, and pessimistic time values, Table B1, are based on either historical data or a jury of executives. Once the predecessor-follower relations are defined between activities, the PERT/CPM model gives information on critical path(s), variances, expected time of completion, and standard deviation (see Table B2). In the

F-14 overhaul process, the critical path follows the sequential steps of defuel, induction, strip, initial/assembly, clean and select disassembly. Then, in the simultaneous activities, the path continues with airframe fuselage, NDI, assembly, checkout/test, paint, fuel, and ground check/flight test. The overall duration for project completion is estimated at 188.5 days with a standard deviation of 4.05 days on the critical path.

This information is useful for the process improvement. From a schedule perspective, not only the estimated completion time be estimated, but also the probability of completion to target date. If the target is 200 days, by applying the standard normal approximation, there is a probability of 97.8% that the project will be completed within target. This is particularly useful when bidding on a schedule-sensitive contracts that have incentives or penalties associated with completion time. The expected penalty/bonus is the expected value based on the probability of failure/success.

From the management perspective, tradeoffs between time/cost may be reached. To accelerate a project, additional resources may be assigned to the critical path at the expense of incurring more direct labor cost. But the benefit of reducing the project duration and associated indirect labor cost may be more cost effective. The ex-

ecutive board may plan a target goal for QMB/PAT to do, check the progress, then act from the feedbacks for further improvement. This technique, once mastered, may be transferred to future projects such as the A-6 competition.

APPENDIX C

Quality loss is the financial loss imparted to the company or society after a product is shipped. It can represent opportunity cost of foregone profits or the cost to rework or replace an item. The loss is measured as cost versus variation to specifications. For example, two products that are designed to perform the same function may both meet specifications, but can cause different losses to the product or system. This concept is graphically portrayed in Figure C1, which shows that simply meeting "spec" is a poor measure or quality. It also implies that there is little significance between being just inside or just outside the specification limit.

Taguchi's powerful concept of Quality Loss Function is expressed through a quadratic relationship that comes from a Taylor series expansion: L=K(y-m)2. Derivations of this equation can be used in determining average process loss. The loss coefficient (K) can be computed based on known incremental losses for given conditions, such as penalty costs from warranties, loss of business, processing customer complaints, etc. Once the coefficient is known, the expected incremental quality loss can be determined and plotted as points on a parabolic curve. Hence, the further away from the target value, the higher the loss is anticipated to be as the spec limit is approached or exceeded.

Quality Loss Functions form the basis for design of experiments which are a repetitive process of evaluating ideas to reduce variation and optimize the product. The application of design of experiments has substantially contributed to the Japanese quality evolution as shown in Figure C2. While this concept has only some applications in the Naval Aviation Depot current mission, the future could be much different. Depots can develop new workload and product mixes under aggressive business planning activities. A cadre of engineers and technicians under the TQM philosophy could be dedicated to reducing process variation and providing feedback to the supply system/suppliers for revisions of component tolerance criteria.

BIBLIOGRAPHY

Atkinson, P.E. and J. Naden, "Total Quality Management: Eight Lessons to Learn From Japan", Management Services, 33, March, 1989.

Barker, T.B., and D.P. Clausing, "Quality Engineering By Design - The Taguchi Method", 40th Annual RSQC Conference, 6 March, 1984.

Burgham, P.M., "Design of Experiments - The Taguchi Way", Manufacturing Engineering, May, 1985.

Burstein, C. and K. Sedlak, "The Federal Quality and Productivity Improvement Effort", Quality Progress, 21, October, 1988.

Dannenbring, D.G. and M.K. Stann, "Management Science: An Introduction", New York, McGraw-Hill, 1981.

Deming, Dr. W.E., "Improvement of Quality and Productivity Through Action By Management", National Productivity Review, Winter 1981-82.

Deming, W.E., Quality, Productivity, and Competitive Position. Cambridge MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study, 1982.

Deming Method Consulting Group, "Manual For Training In The Deming Method", Miami, FL, 1985.

Dennis, T.L. and L.B. Dennis, "Microcomputer Models for Management Decision Making", 2nd Edition, St. Paul, MN, West Publishing Company, 1985.

Department of Defense, DoD Directive on Total Quality Management, 1989.

Department of Defense, Total Quality Management Guide, August 1989.

Department of Defense, Total Quality Management Implementation: Selected Readings, April 1989.

Department of Defense, Total Quality Management Master Plan, Washington, D.C., August 1988.

Dilworth, James B., Production and Operations Management. New York: Random House, 1989.

Dockstader, S.L. and A. Houston, A Total Quality Management Process Improvement Model, San Diego, Navy Personnel Research and Development Center, December, 1988.

Fargher, Jr., J.S., "Productivity Improvement Causes Constant Change", Program Managers, May - June, 1989.

Gartman, Col. J.B. and J.S.W. Fargher, Jr., "Implementing Gainsharing in a Total Quality Management En-

vironment", Institute of Industrial Engineers Conference and Proceedings, 1988.

Garving, D.A., "Quality On The Line", Harvard Business Review, September-October 1983.

Garving, D.A., "What Does "Product Quality" Really Mean?", Sloan Management Review, Fall 1984.

Gitlow, H.S. and P.T. Hertz, "Product Defects and Productivity", Harvard Business Review, September-October 1983.

Ishikawa, Kaoru, Guide to Quality Control, Tokyo, Japan: Asian Productivity Organization, 1985.

Jessup, P., "The Value of Continuing Improvement", Institute of Electrical and Electronic Engineers, Inc. for publication in the proceedings of The International Communications Conference, June 1985.

Katzen, J., "Katzen on Quality", Dimensions, June 1988.

Kennedy, P., "The (Relative) Decline of America", The Atlantic Monthly, August 1987.

Leonard, F.S. and W.E. Sasser, "The Incline of Quality", Harvard Business Review, September-October 1982.

Scholtes, P.R. and H. Hacquebord, "Beginning The Quality Transformation, Part I", Quality Progress, July 1988.

Scholtes, P.R. and H. Hacquebord, "Six Strategies for Beginning The Quality Transformation, Part II", Quality Progress, August 1988.

Siesel, J.C., "Managing With Statistical Methods", SAE Technical Paper Series, Society of Automotive Engineers, Inc., 1982.

Stuelpnagel, T.R., "Total Quality Management in Business - Academia", Business Forum, 14 (Fall 1988/Winter 1989).

Sullivan, L.P., "Reducing Variability: A New Approach to Quality", Quality Progess, July 1984.

Sullivan, L.P., "Company-Wide Quality Control For Automobile Suppliers", Ford Motor Company, 1985.

Tribus, M. and Y. Tsuda, "Creating The Quality Company", Massachusetts Institute of Technology, Center for Advanced Study, 1983.

ORGANIZATION STRUCTURE

SPAN-OF-CONTROL

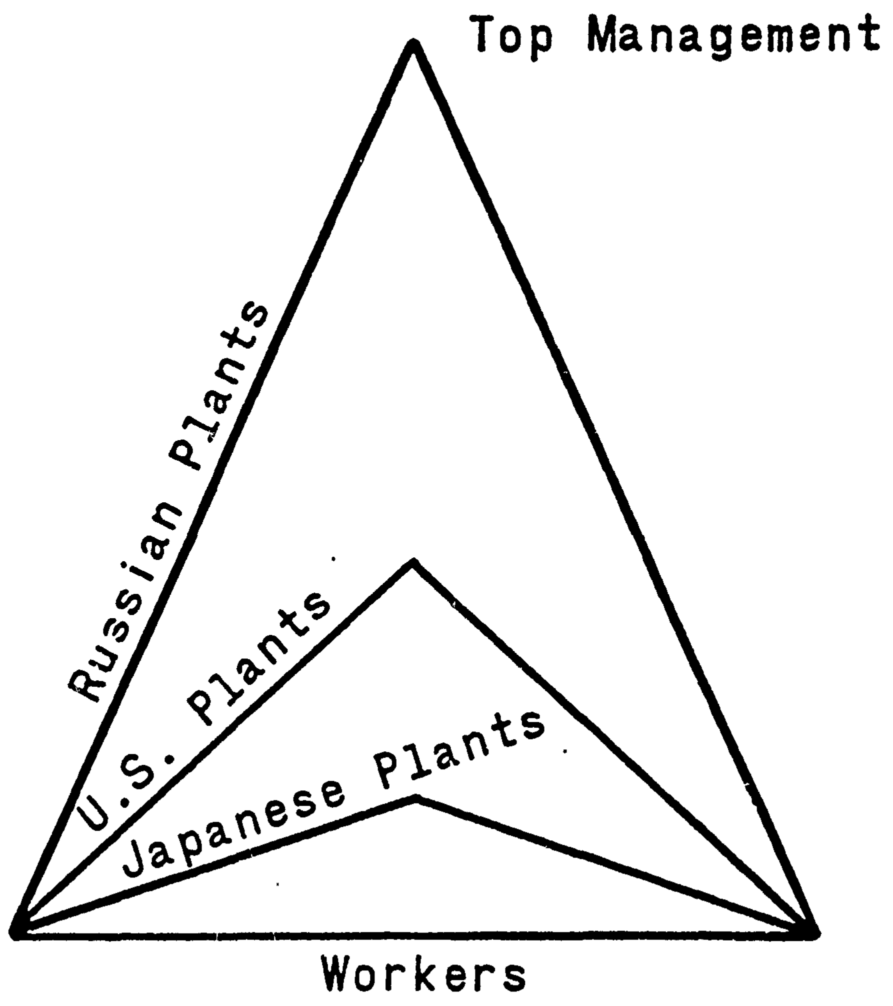
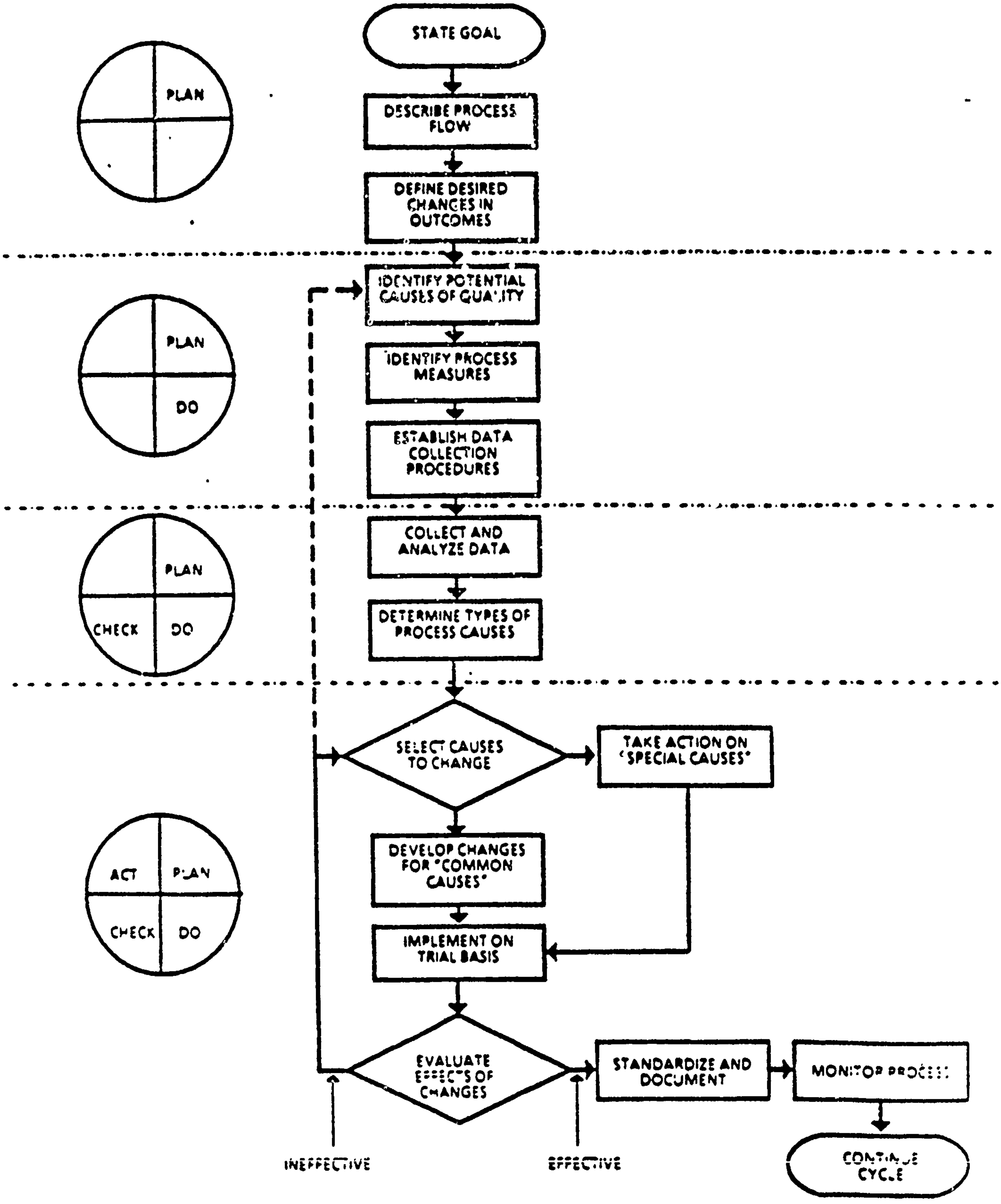


Figure 1



Process improvement model for total quality management.

Figure 2

FIVE STAGES OF THE DEMING PHILOSOPHY

STAGE 1: Create a Positive Environment

STAGE 2: Define the Process

STAGE 3: Identify Process Characteristics

STAGE 4: Monitor and Control the Process

STAGE 5: Improve the Process

Figure 3

MEETING THE MANAGERIAL CHALLENGE
OF
IMPLEMENTING THE DEMING PHILOSOPHY

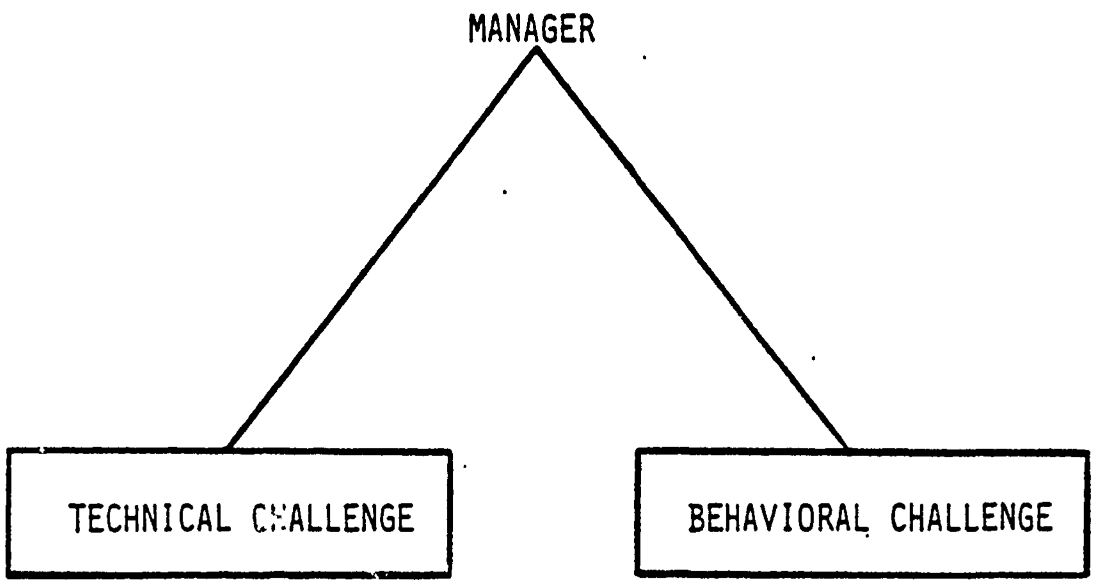
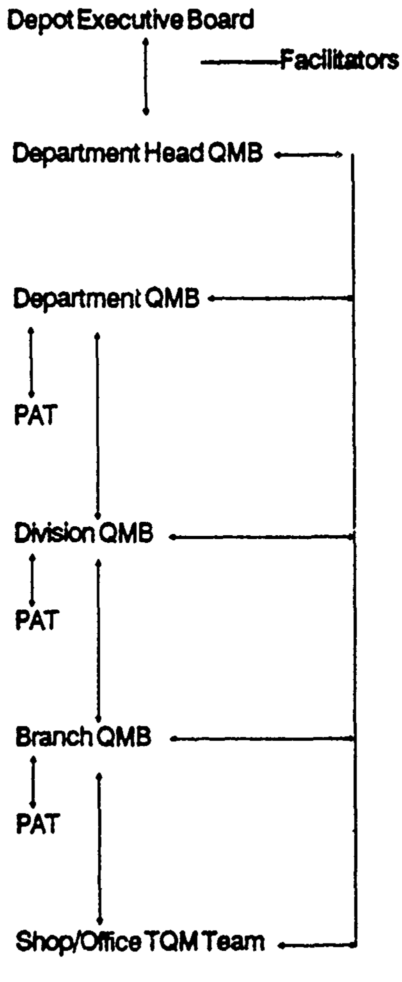


Figure 4

TQM ORGANIZATION COMMUNICATION FLOW

The following diagram shows a typical TQM organization setup at a Naval Aviation Depot. The lines of communication from the Depot Executive Board (DEB), which represents the top management policy and decision-making group, flow down via the chain of command to the shop/office worker. In particular, the activities among the various Quality Management Boards (QMBs) and Process Action Teams (PATs) must be established and maintained for effective coordination. Likewise, under the NADEP Commanding Officer (equivalent to Chief Executive Officer or CEO), the DEB must provide the essential guidance and vision for successful TQM implementation.



In this capacity, the DEB performs the functions of the TQM Executive Steering Committee (ESC).

Figure 5

LABOR RATE REVIEW
(REDEFINED COST CENTERS)

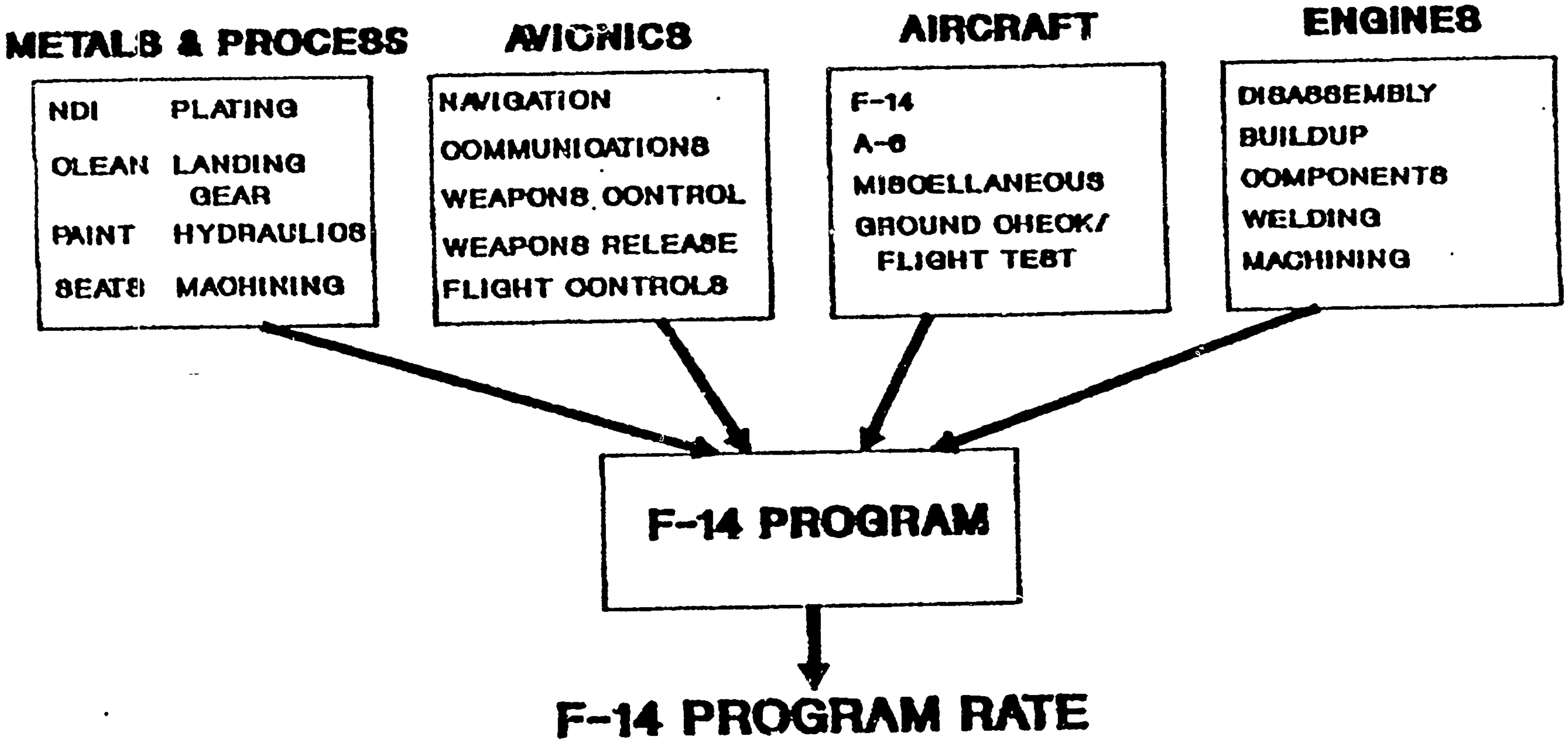


Figure 6

LABOR RATE REVIEW
(REDEFINED COST CENTERS)

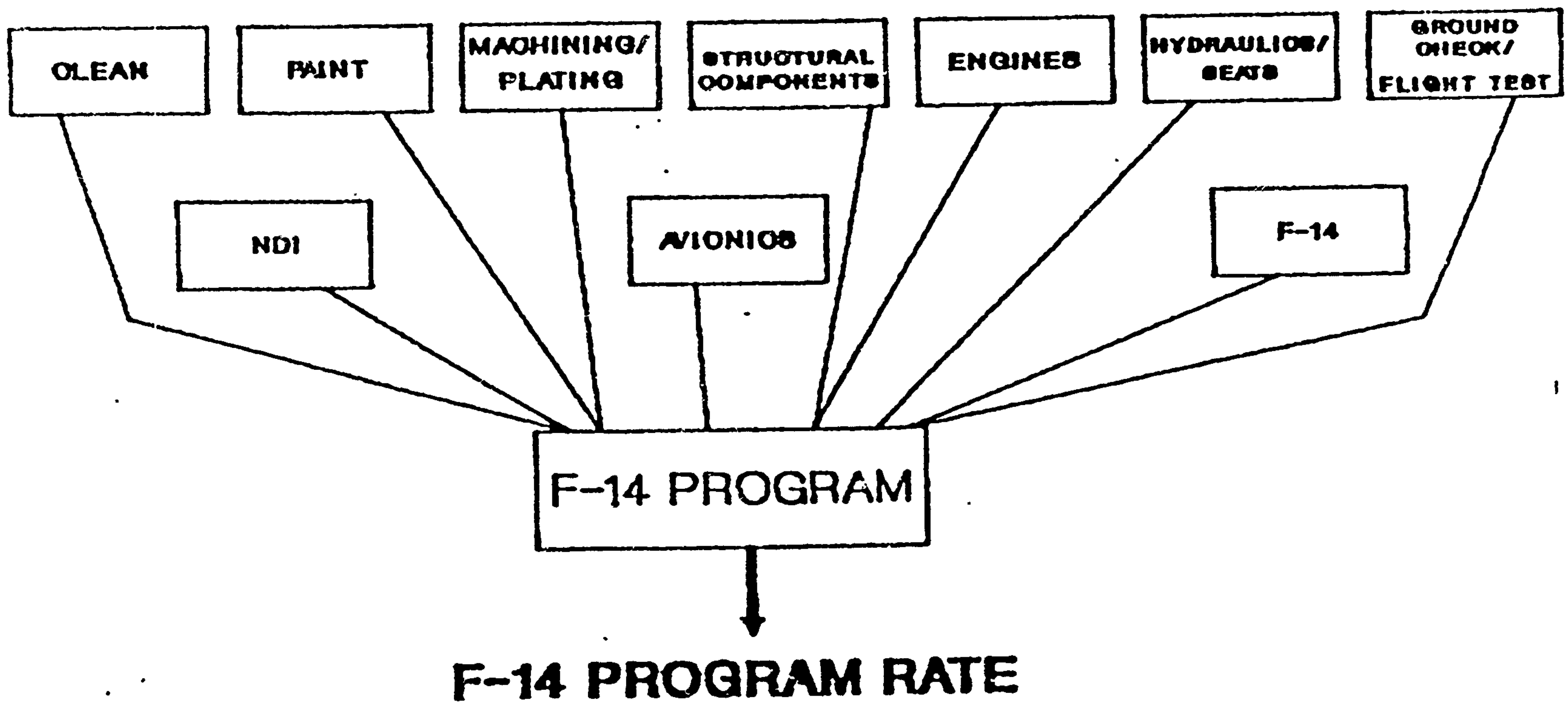


Figure 7

RESULTS

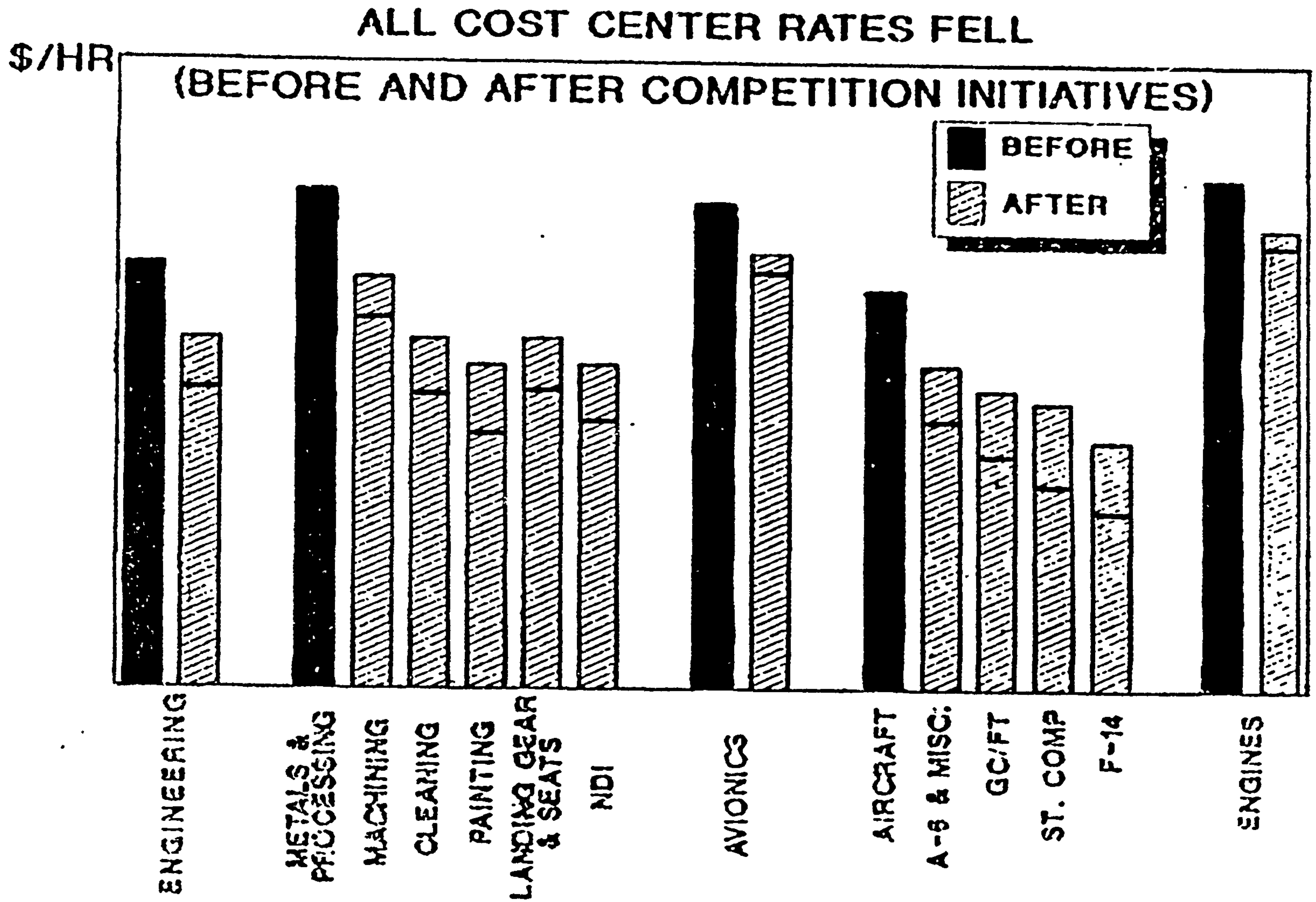


Figure 8

TRADITIONAL METHOD OF PRODUCT QUALITY

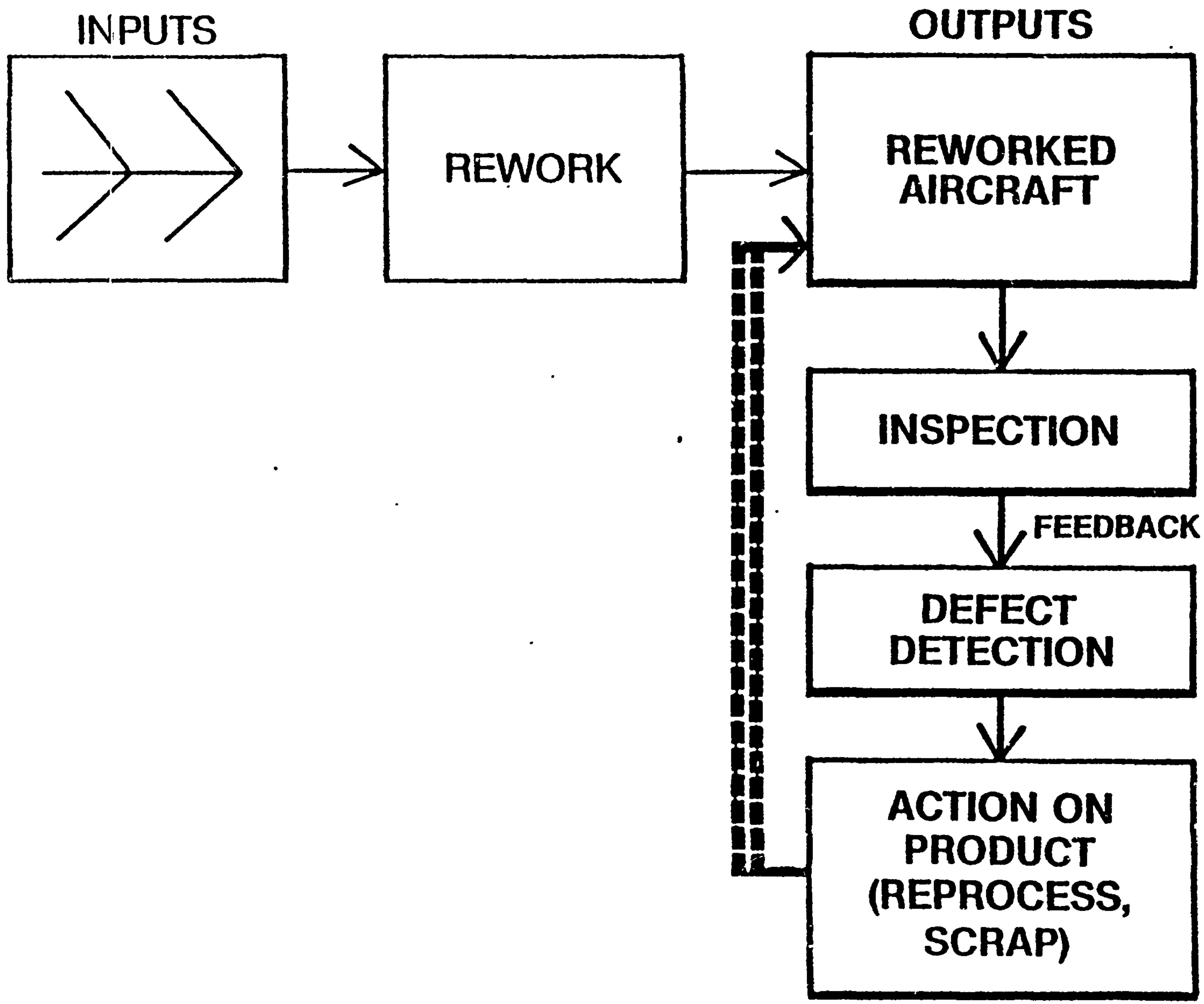


Figure 9

TRADITIONAL METHOD OF PRODUCT QUALITY

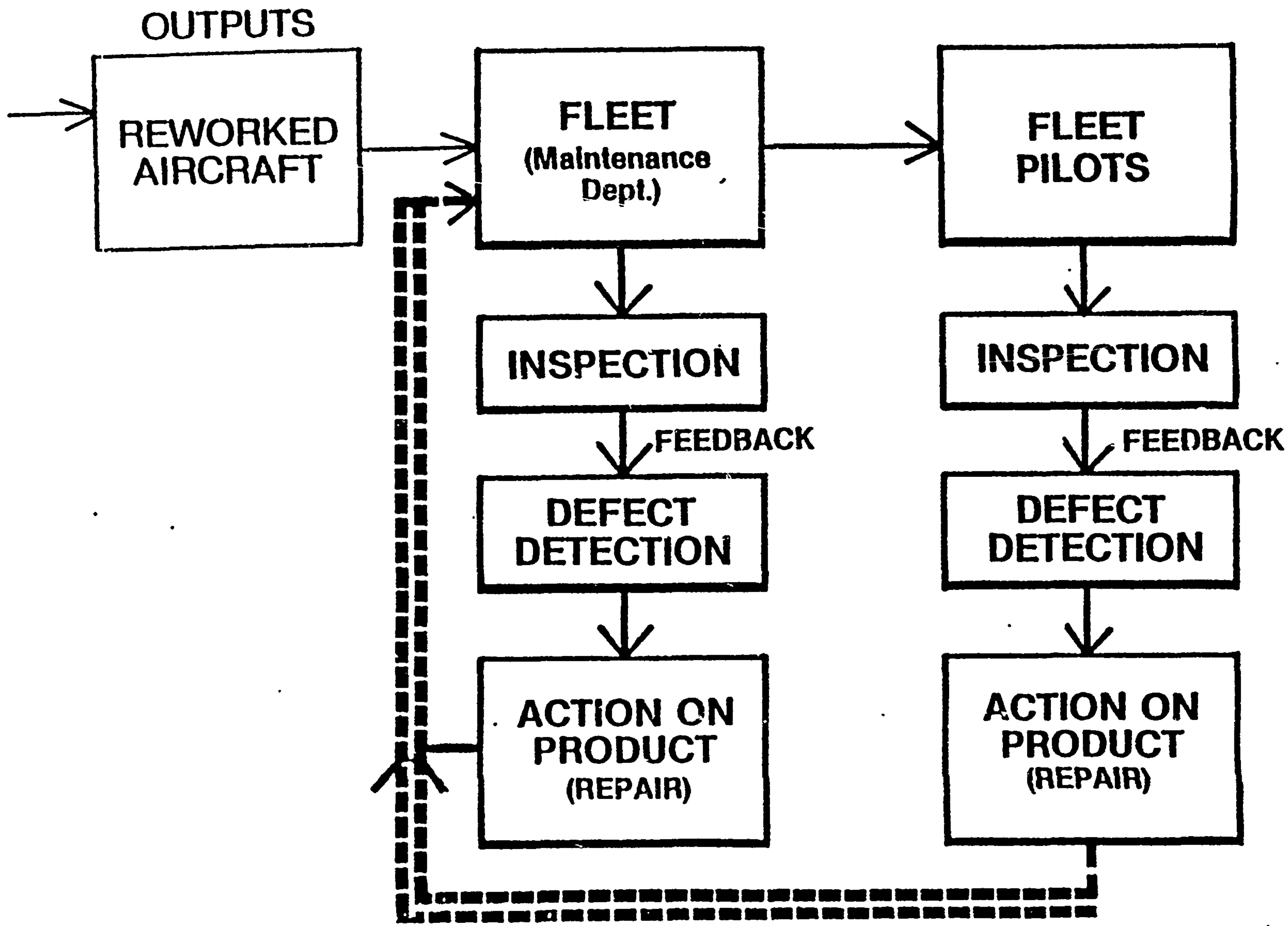


Figure 10

DEMING METHOD OF PRODUCT QUALITY

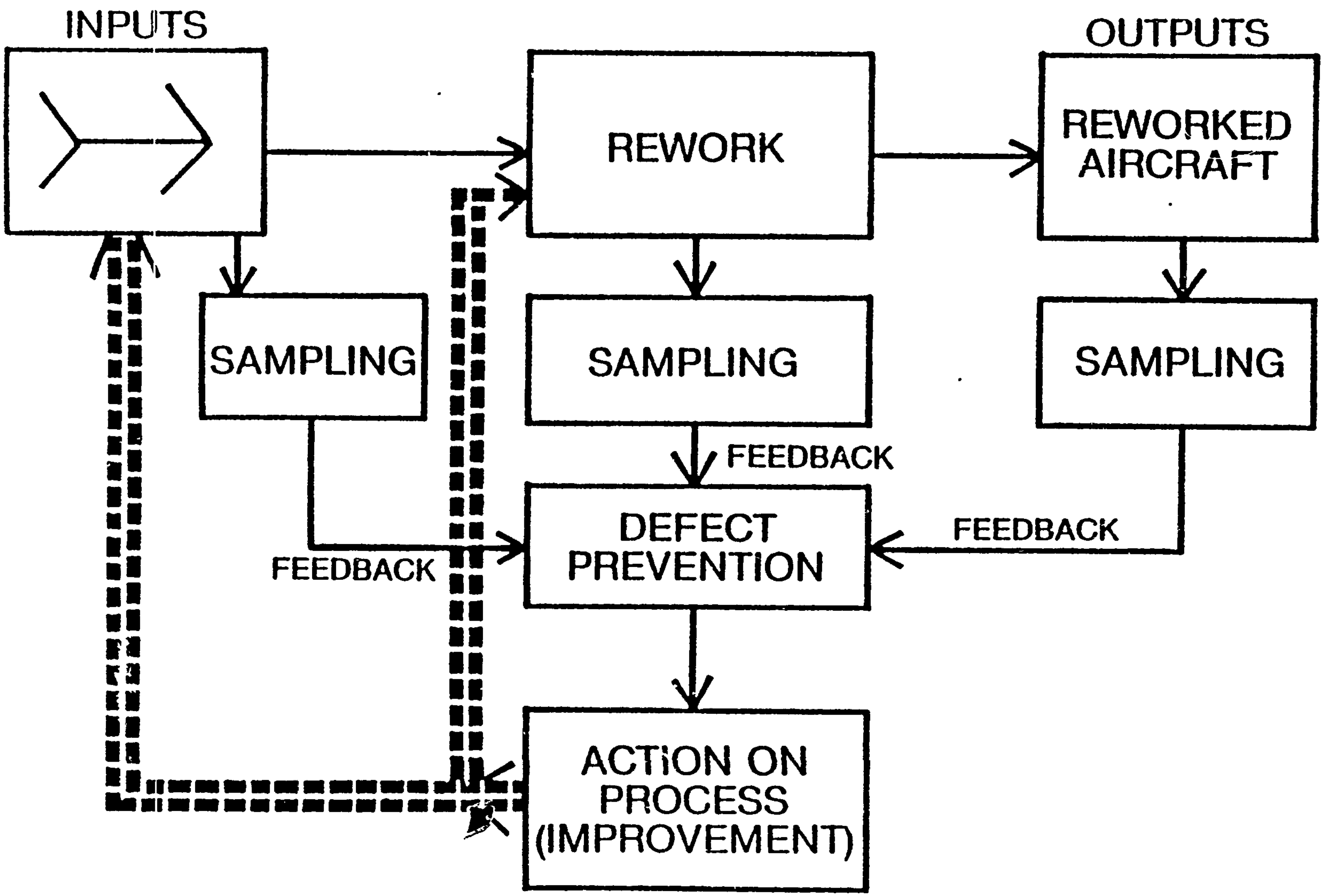


Figure 11

TYPICAL TOTAL QUALITY MANAGEMENT MODEL

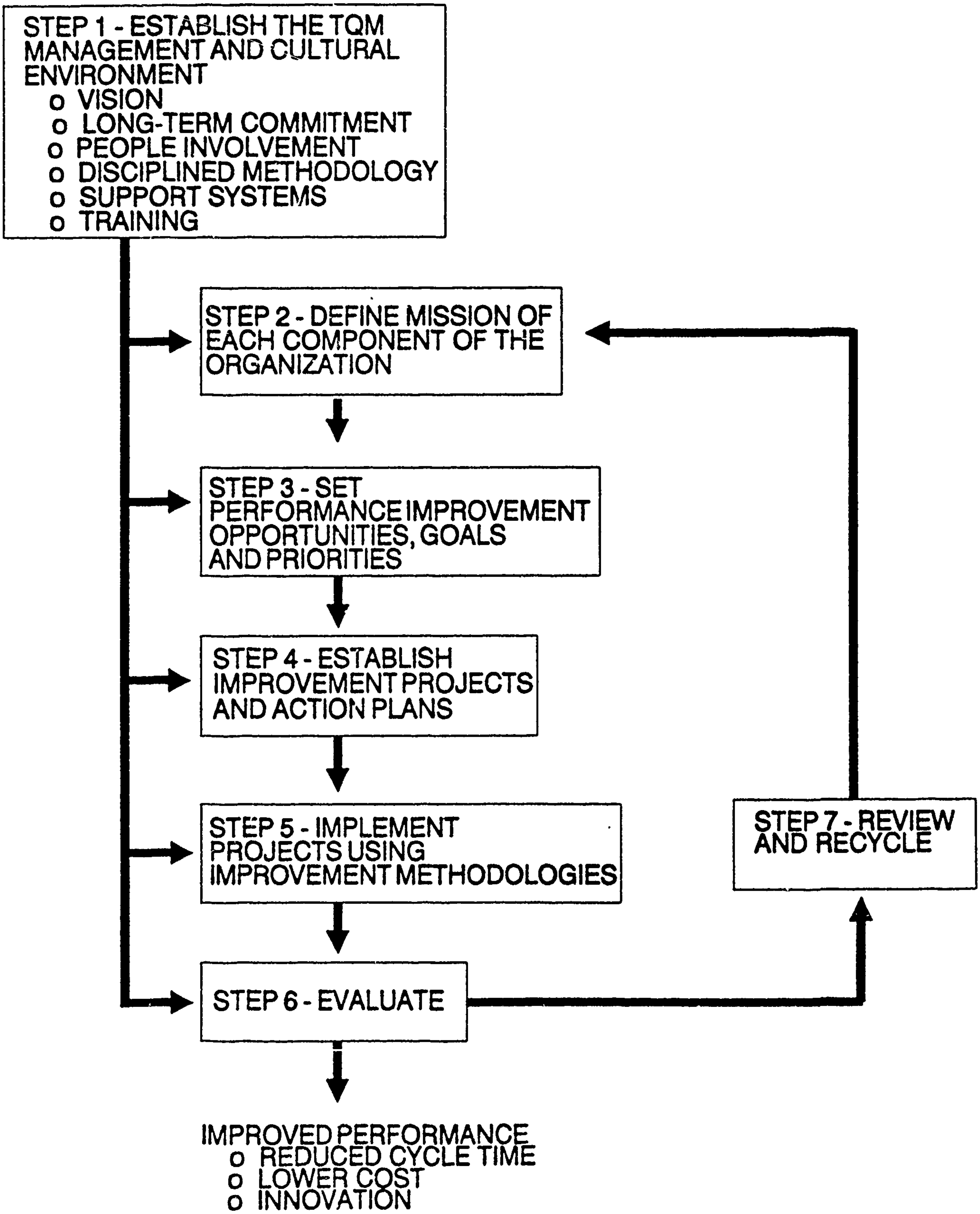


Figure 12

Step 4
Establish Improvement Projects and Action Plans

Steering Group	Improvement Teams	Problem Solving Teams
Focus on Critical processes	Set Task Goals	Apply a structured performance improvement methodology
	Conduct analyses	
Resolve organizational and functional barriers	Select teams	
Provide resources, training and rewards	Train teams	
Establish measurement criteria	Develop improvement plans and methodologies	
Monitor progress toward goals	Track progress	

Senior management ⟶ ⟶ ⟶ ⟶ Workforce

(Cross-functional) (Speciality areas)

Figure 13

STEP 5
IMPLEMENT PROJECTS WITH PERFORMANCE TOOLS AND METHODOLOGIES

BASIC PERFORMANCE IMPROVEMENT CYCLE

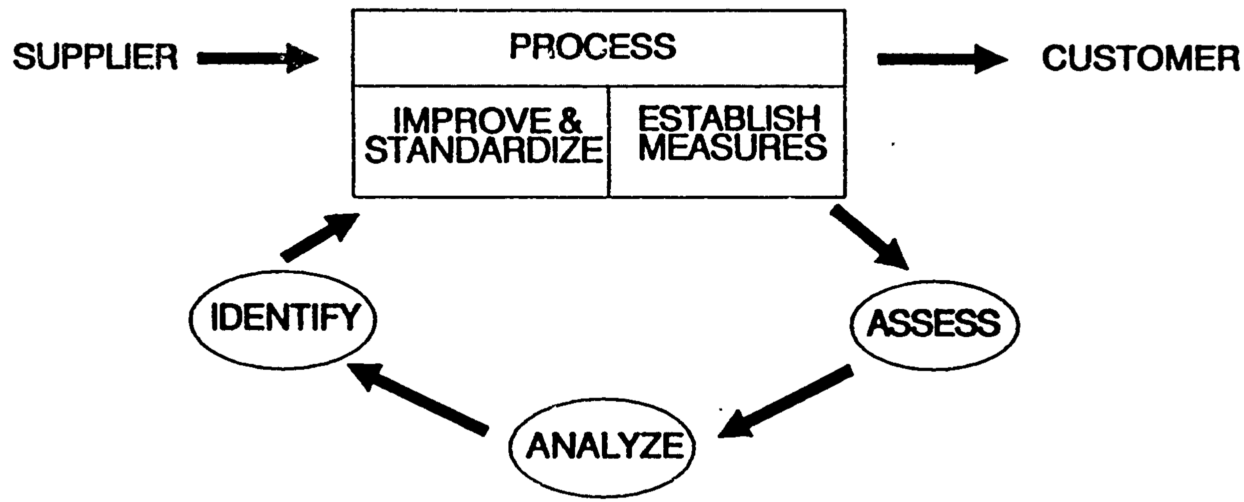
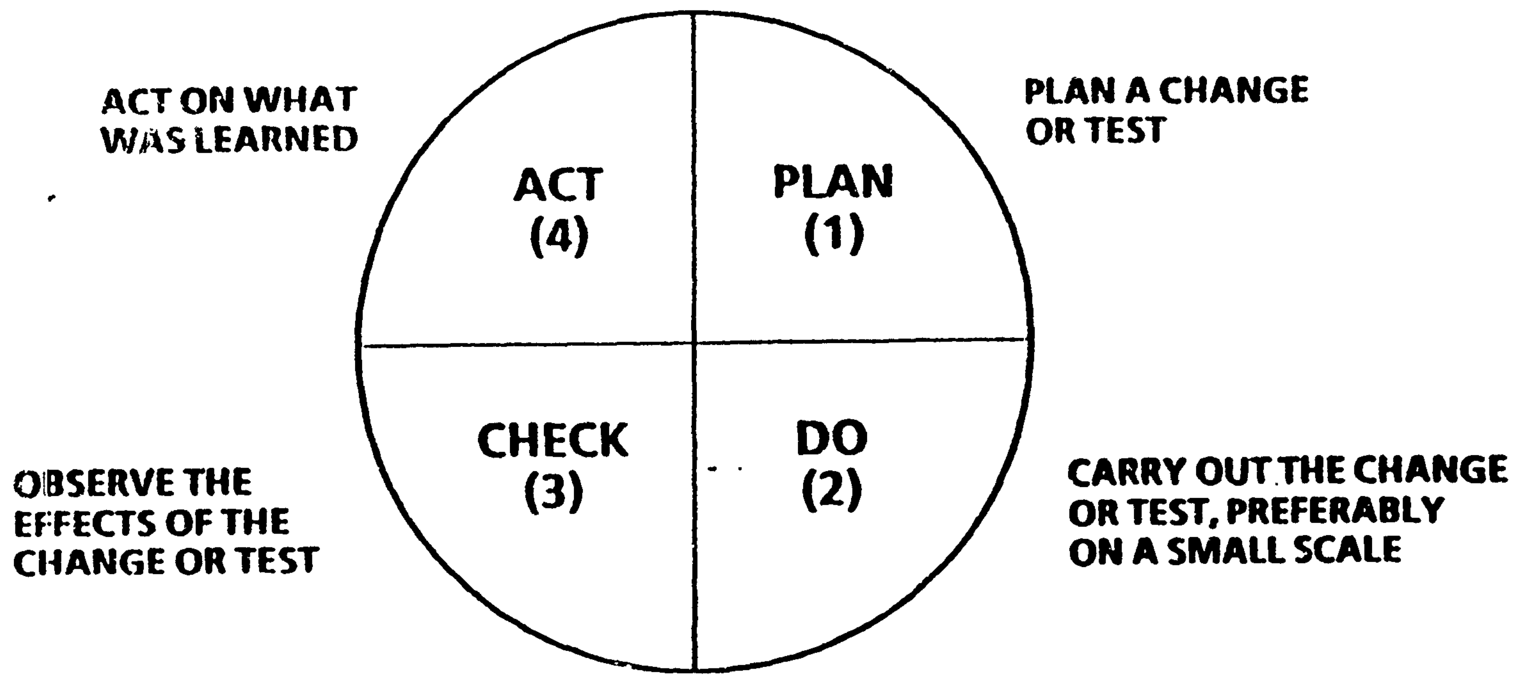


Figure 14

THE SHEWHART CYCLE
(Deming, 1986)



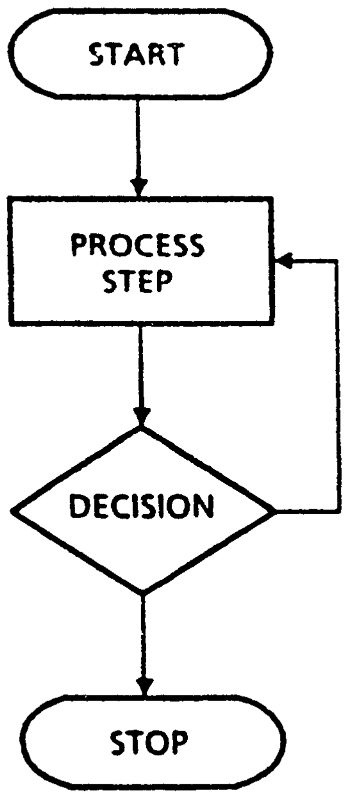
5. REPEAT STEP 1, WITH NEW KNOWLEDGE.
6. REPEAT STEP 2, AND ONWARD.

Figure 15

STATISTICAL PROCESS CONTROL TOOLS

- FLOW CHART
- PARETO DIAGRAM
- FISHBONE DIAGRAM
- HISTOGRAM
- SCATTER PLOT
- CONTROL CHART

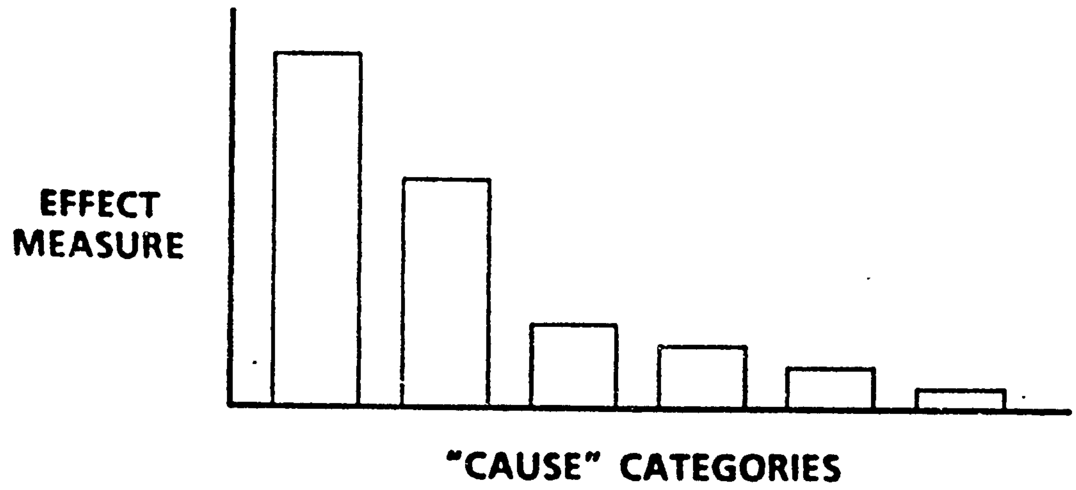
Figure 16



- LINES AND SYMBOLS CHART
- REPRESENTS MAJOR STEPS OF A PROCESS
- FORMS BASIS FOR IDENTIFYING EXCESSIVE COMPLEXITY AND WASTE

Process flowchart.

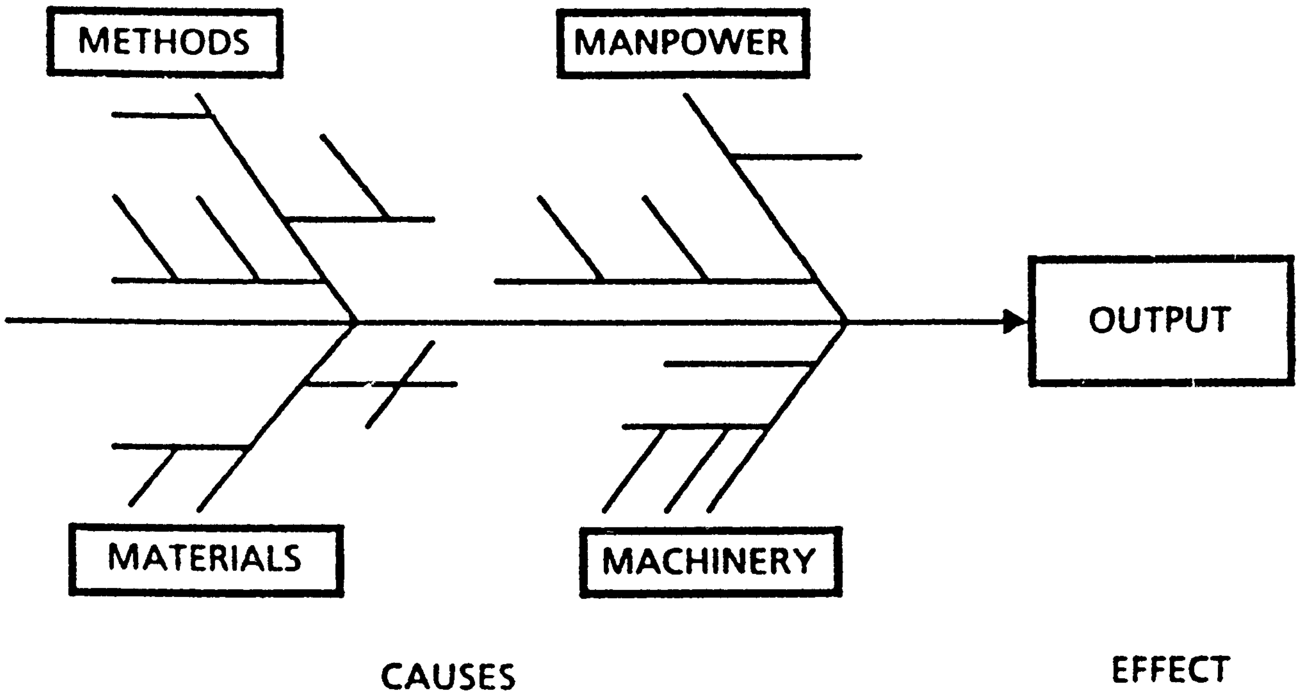
Figure 17



- VERTICAL BAR GRAPH OF DISCRETE DATA
- USED TO RANK IMPORTANCE OF CAUSES
- AIDS IN SELECTING IMPROVEMENT AREAS

Pareto chart.

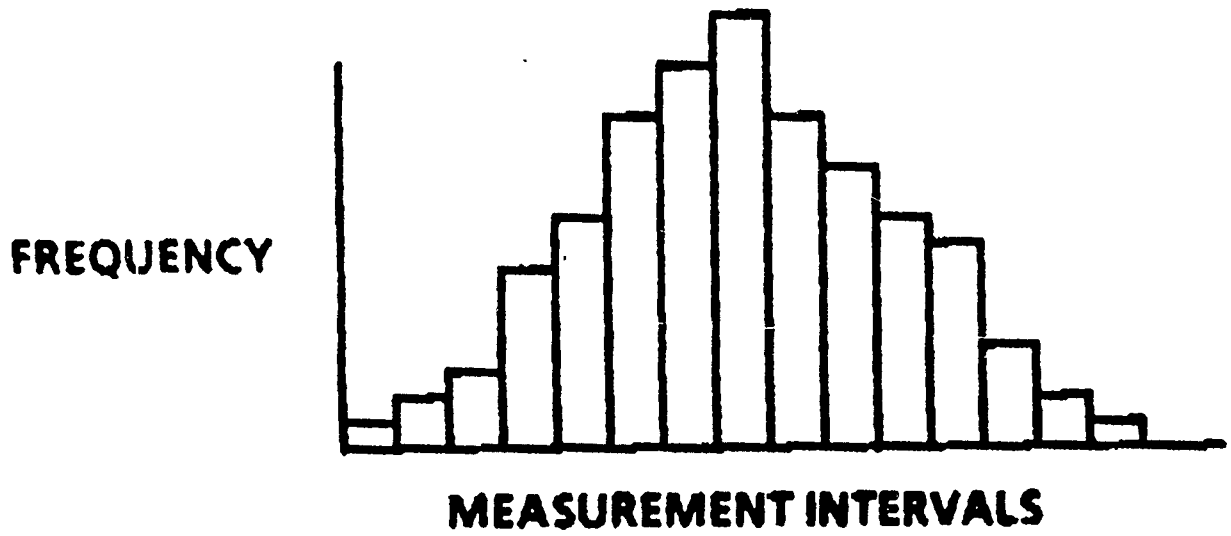
Figure 18



- BRAINSTORMING COMBINED WITH BRANCHING DIAGRAM
- LISTS POSSIBLE CAUSES FOR GOOD OR BAD QUALITY
- SHOWS RELATIONSHIP BETWEEN "EFFECT" AND ITS "CAUSES"
- AIDS IN ANALYZING COMPLEX INTERACTIONS

Cause-and-effect analysis chart.

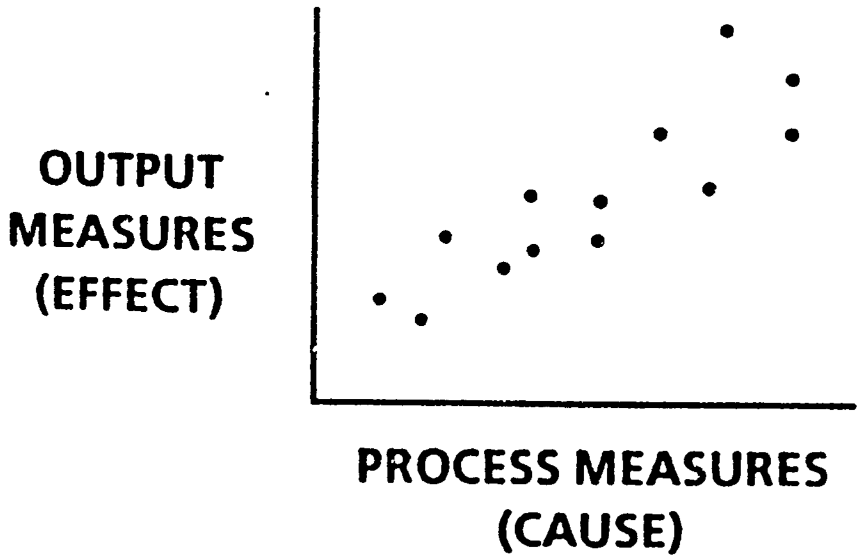
Figure 19



- BAR GRAPH OF CONTINUOUS DATA
- DISPLAYS AMOUNT AND TYPE OF VARIATION IN PROCESS OUTPUTS

Histogram.

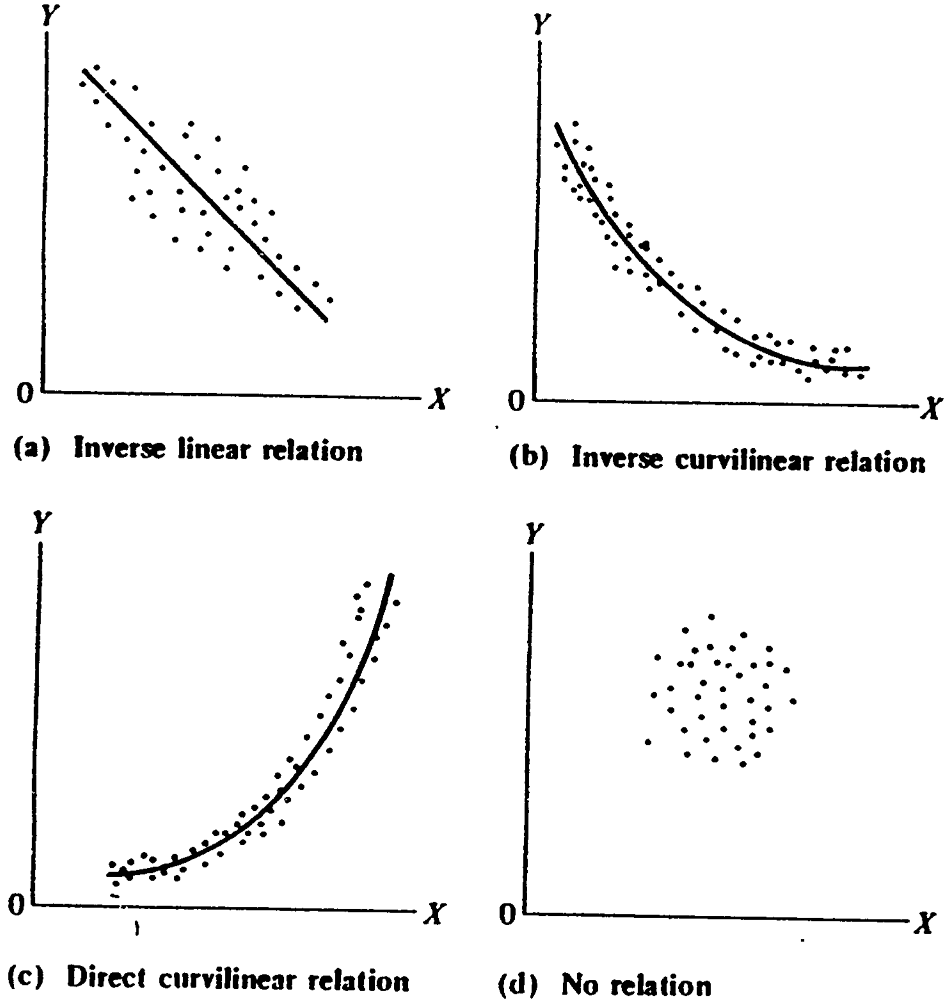
Figure 20



- SCATTER PLOT OF PAIRED MEASUREMENTS
- USED TO TEST RELATIONSHIP BETWEEN A SUSPECTED "CAUSE" AND THE OUTPUT EFFECT

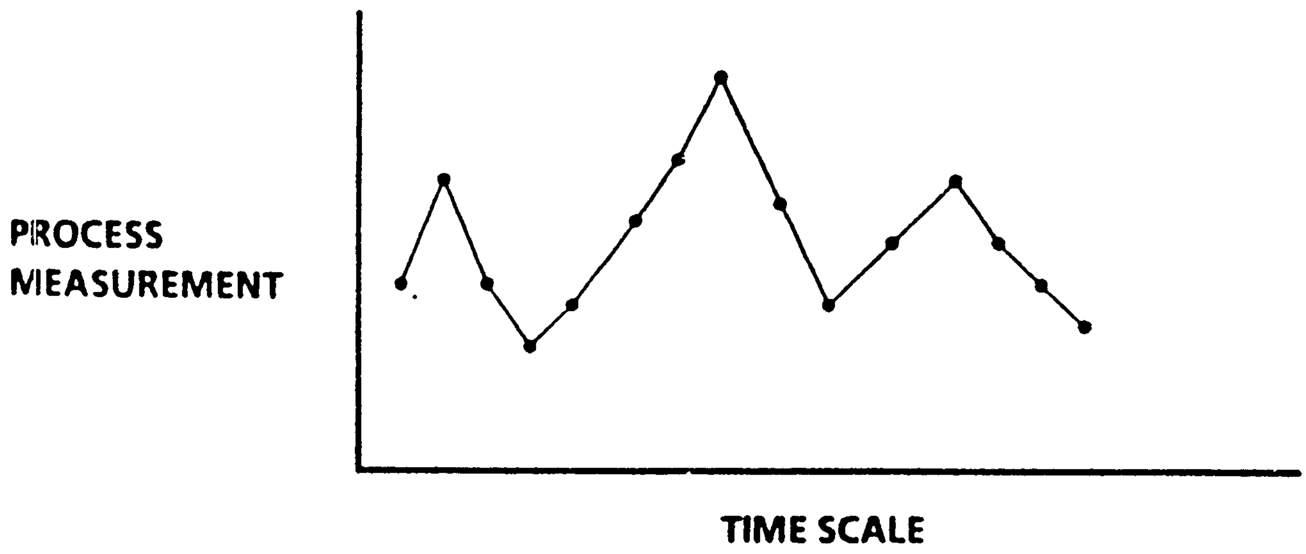
Scatter diagram.

Figure 21



Scatter diagrams

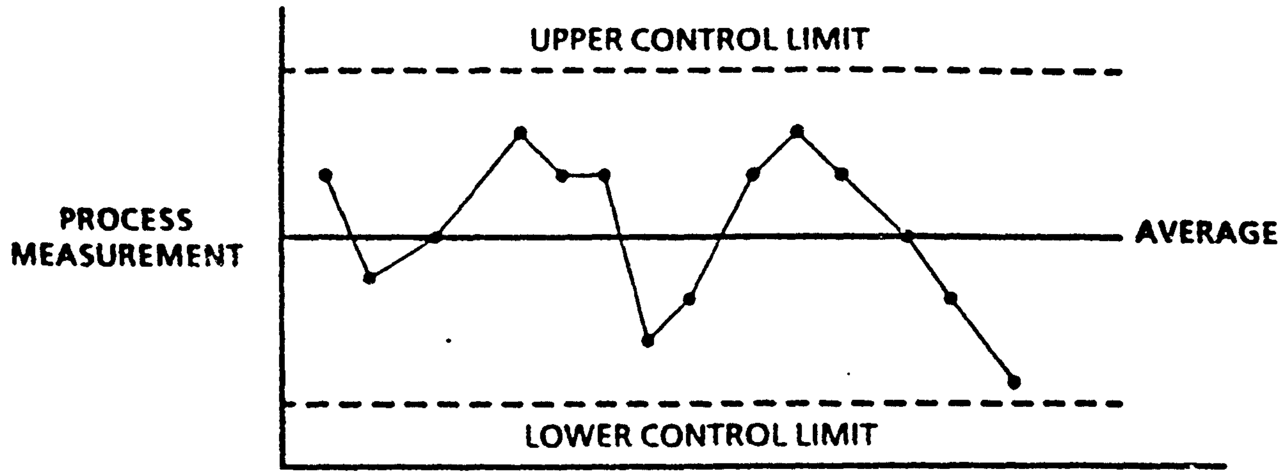
Figure 22



- LINE GRAPH
- SIMPLE DISPLAY OF PROCESS PERFORMANCE OVER TIME

Run chart.

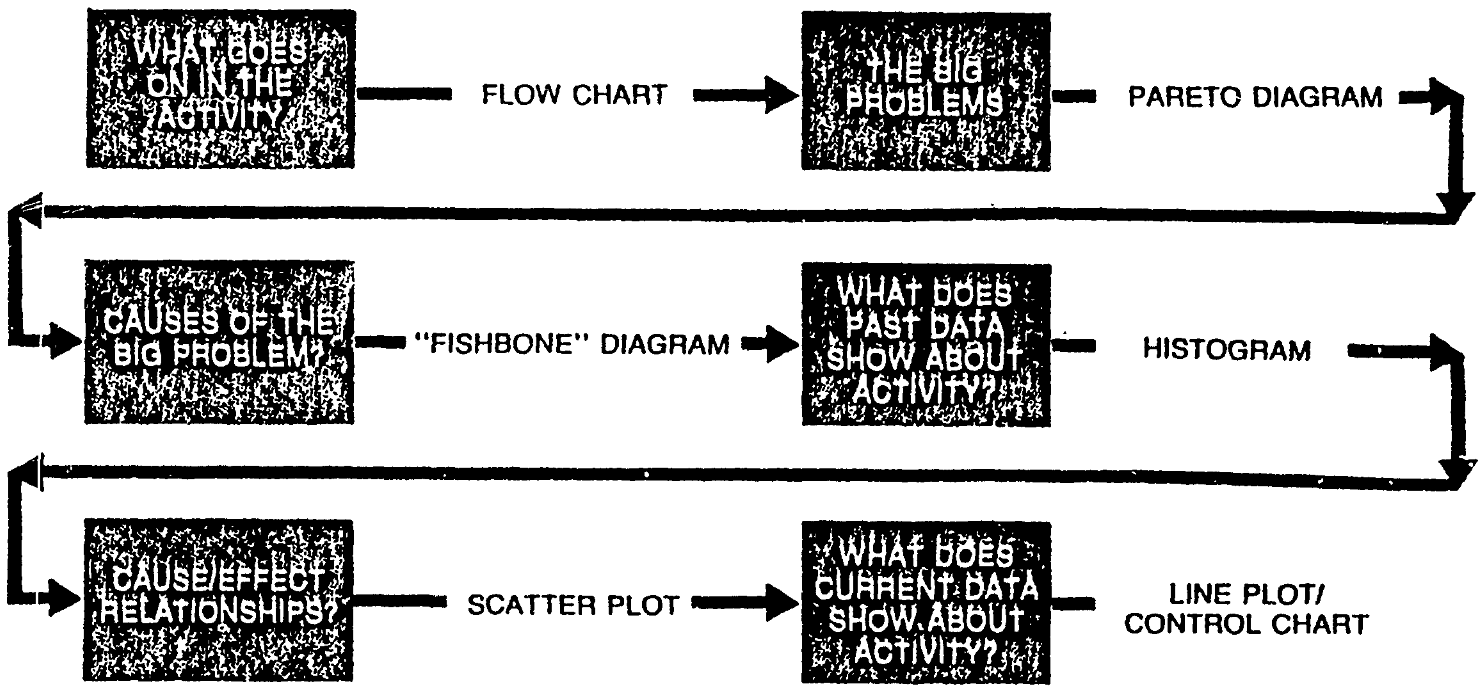
Figure 23



- LINE GRAPH WITH ESTIMATED PERFORMANCE PARAMETERS
- EVALUATES STABILITY OF A PROCESS
- DIAGNOSES PROBLEMS (PROBLEM ANALYSIS)
- ASSESSES EFFECTS OF IMPROVEMENT ACTIONS (PROCESS CONTROL)

Control chart

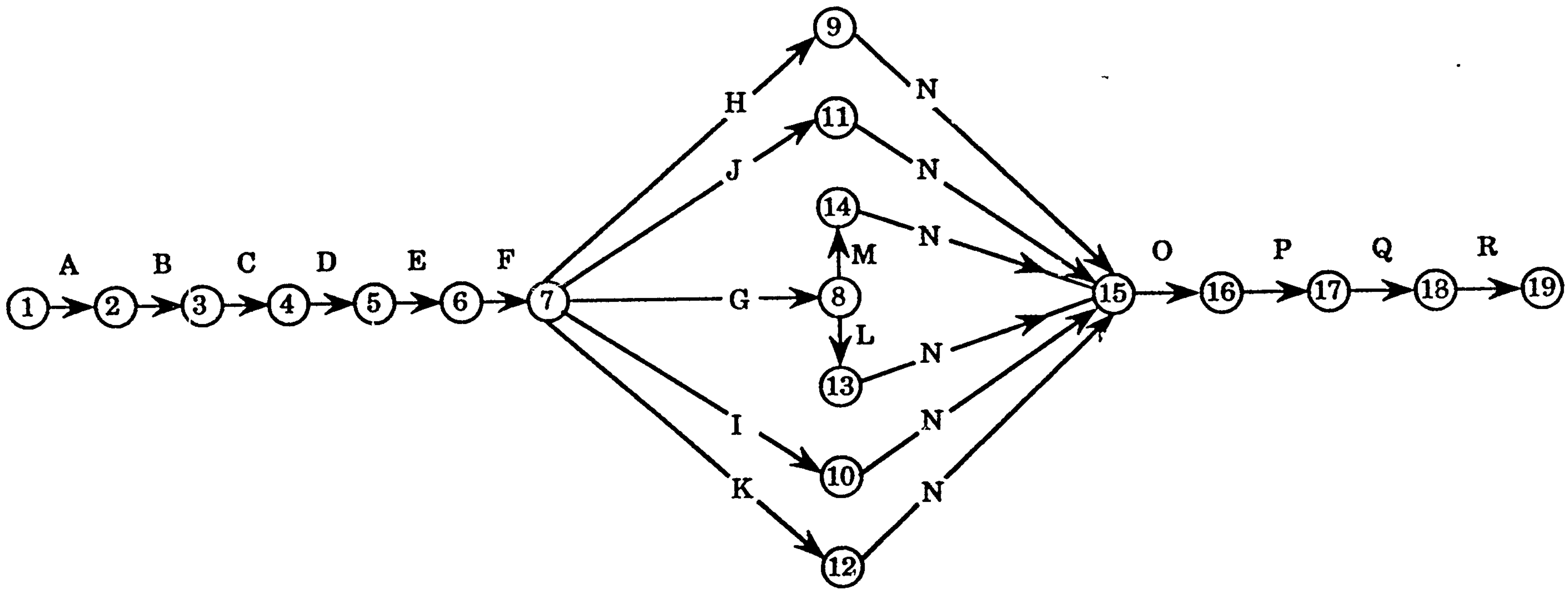
Figure 24



ROLE OF STATISTICAL PROCESS CONTROL IN TOTAL QUALITY MANAGEMENT

Figure 25

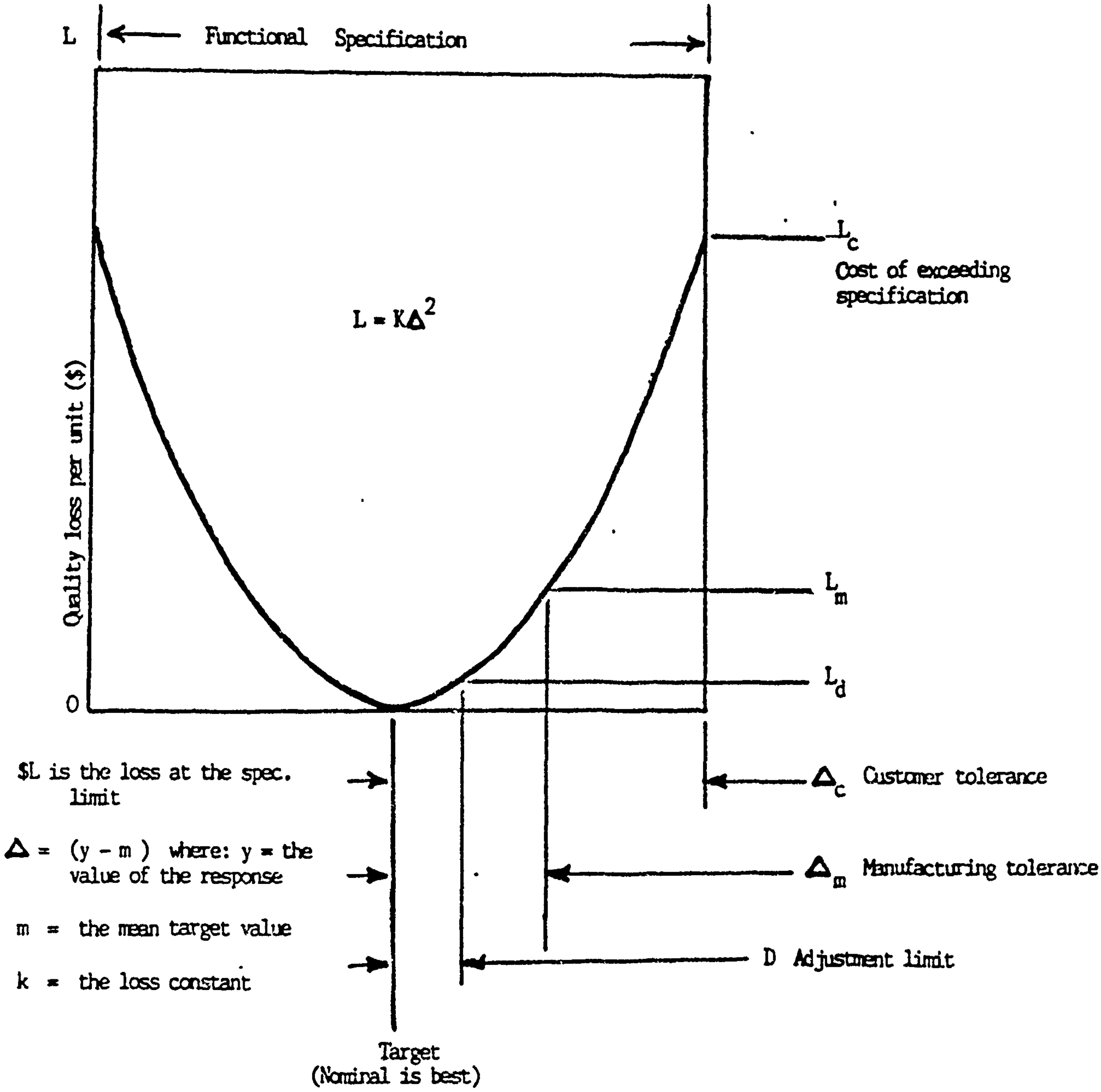
F-14
STANDARD DEPOT LEVEL MAINTENANCE
SEQUENCE OF ACTIVITIES



A DEFUEL
B INDUCTION
C STRIP
D INITIAL DISASSEMBLY
E CLEAN
F SELECT DISASSEMBLY
G AIRFRAME FUSELAGE
H STRUCTURAL COMPONENTS
I ENGINES
J HYDRAULICS / SEATS
K AVIONICS
L MACHINING
M NDI
N ASSEMBLY
O CHECKOUT / TEST
P PAINT
Q FUEL
R GROUND CHECK / FLIGHT TEST

Figure B1

QUALITY LOSS FUNCTION



The above diagram represents the cost of quality within the upper and lower limits of the specification to achieve customer acceptance (customer tolerance). Economical satisfaction of specification requires that a three-tiered system of tolerances exist.

Figure C1

JAPANESE QUALITY EVOLUTION

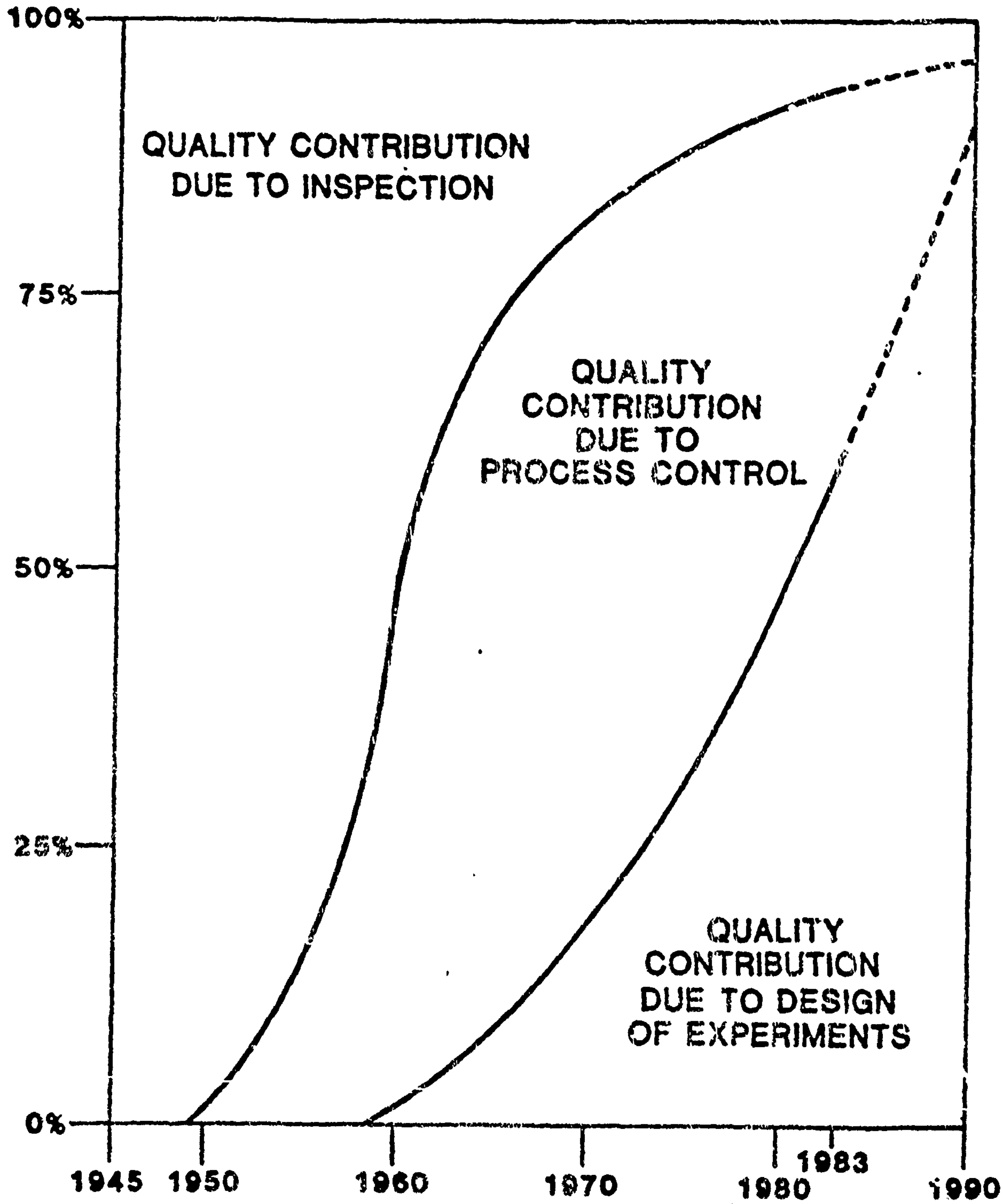


Figure C2

```
*************************************
*                                   *
*           PERT ANALYSIS           *
*                                   *
*************************************
```

PROBLEM: F-14

HERE IS WHAT YOU ENTERED:

ACTIVITY	IMMEDIATE PREDECESSORS	OPTIMISTIC TIME	MOST LIKELY TIME	PESSIMISTIC TIME
A	-	1	1	1
B	A	1	1	1
C	B	1	1	2
D	C	3	4	5
E	D	1	1	1
F	E	10	12	15
G	F	41	52	59
H	F	72	75	80
I	F	49	56	60
J	F	66	70	74
K	F	44	54	65
L	G	26	39	54
M	G	36	40	45
N	H,I,J,K,L,M	35	37	41
O	N	10	13	16
P	O	3	4	5
Q	P	1	3	5
R	Q	16	19	24

Table B1

OUTPUT: PROBABILISTIC, LETTERED ACTIVITIES & PREDECESSORS

ACTIVITY	IMMEDIATE PREDECESSOR	EXPECTED (t)	VAR
A	-	1.00	0.00
B	A	1.00	0.00
C	B	1.17	0.03
D	C	4.00	0.11
E	D	1.00	0.00
F	E	12.17	0.69
G	F	51.33	9.00
H	F	75.33	1.78
I	F	55.50	3.36
J	F	70.00	1.78
K	F	54.17	12.25
L	G	39.33	21.78
M	G	40.17	2.25
N	H,I,J,K,L,	37.33	1.00
O	N	13.00	1.00
P	O	4.00	0.11
Q	P	3.00	0.44
R	Q	19.33	1.78

ACT	EARLY START	LATE START	EARLY FINISH	LATE FINISH	SLACK (LS-ES)	CRITICAL PATH
A	0.0	-0.0	1.0	1.0	0.0	YES
B	1.0	1.0	2.0	2.0	0.0	YES
C	2.0	2.0	3.2	3.2	0.0	YES
D	3.2	3.2	7.2	7.2	0.0	YES
E	7.2	7.2	8.2	8.2	0.0	YES
F	8.2	8.2	20.3	20.3	0.0	YES
G	20.3	20.3	71.7	71.7	0.0	YES
H	20.3	36.5	95.7	111.8	16.2	
I	20.3	56.3	75.8	111.8	36.0	
J	20.3	41.8	90.3	111.8	21.5	
K	20.3	57.7	74.5	111.8	37.3	
L	71.7	72.5	111.0	111.8	0.8	
M	71.7	71.7	111.8	111.8	0.0	YES
N	111.8	111.8	149.2	149.2	0.0	YES
O	149.2	149.2	162.2	162.2	0.0	YES
P	162.2	162.2	166.2	166.2	0.0	YES
Q	166.2	166.2	169.2	169.2	0.0	YES
R	169.2	169.2	188.5	188.5	0.0	YES

CRITICAL PATH: A-B-C-D-E-F-G-M-N-O-P-Q-R

NETWORK COMPLETION TIME = 188.5
VARIANCE ON CRITICAL PATH = 16.41
STANDARD DEVIATION ON CRITICAL PATH = 4.05

END OF OUTPUT

Table B2

TABLE I

DEMING'S 14 POINTS FOR MANAGEMENT

1. Create constancy of purpose toward improvement of product and service, with a plan to become competitive and to stay in business. Decide whom top management is responsible to.

2. Adopt the new philosophy. We are in a new economic age. We can no longer live with commonly accepted levels of delays, mistakes, defective materials, and defective workmanship.

3. Cease dependence on mass inspection. Require, instead, statistical evidence that quality is built in, to eliminate need for inspection on a mass basis. Purchasing managers have a new job, and must learn it.

4. End the practice of awarding business on the basis of price tag. Instead, depend on meaningful measures of quality, along with price. Eliminate suppliers that cannot qualify with statistical evidence of quality.

5. Find problems. It is management's job to work continually on the system (design, incoming materials, composition of material, maintenance, improvement of machine, training, supervision, retraining, etc.).

6. Institute modern methods of training on the job.

7. Institute modern methods of supervision of production workers. The responsibility of foremen must be changed from sheer numbers to quality. Improvement of quality will automatically improve productivity. Management must prepare to take immediate action on reports from foremen concerning barriers, such as inherited defects, machines not maintained, poor tools/operational definitions.

8. Drive out fear, so that everyone may work effectively for the company.

9. Break down barriers between departments. People in research, design, sales and production must work as a team, to foresee problems of production that may be encountered with various materials and specifications.

TABLE I (Cont'd.)

10. Eliminate numerical goals, posters and slogans for the workforce, asking for new levels of productivity without providing methods.

11. Eliminate work standards that prescribe numerical quotas.

12. Remove all barriers between the worker and his right to pride of workmanship.

13. Institute a vigorous program of education and retraining.

14. Create a structure in top management that will push every day on the above.

TABLE II

Business Sensitive | Business Sensitive

F-14 Competition

Bid Rate Per Aircraft[1] Cost Center	Manhours [2]	Rate/Hr.[3]	Aggregate
F-14			
Miscellaneous*			
Structural Components			
Ground Check/Flight Test		INFORMATION	
Engines		DELETED	
Avionics		FOR	
Clean		PROPRIETARY	
Paint		REASONS	
Machining			
Non-Destructive Inspection			
Quality Assurance			
Engineering			
Production Engineering			
Production Planning			
TOTAL			

*Cost center is hydraulics, landing gear and seats

TABLE III

Steps To Define Mission

1. Identify the customer(s) you serve (do not forget internal customers).

2. Identify the requirements of your customer(s).

3. Identify the processes and resources used to satisfy the requirement.

4. Identify the products or services you provide to meet these requirements.

5. Develop measures of your output that reflect customer requirements.

6. Review the preceding steps with your customer and adjust them as necessary.

7. Identify your principal inputs (labor materials, products, services, etc.).

8. Involve your suppliers in the development of your requirements and their conformance to them.

9. Finally, define your mission with respect to the steps above. If the result does not match your current job description, your job description needs to be changed to reflect your mission. You also need to check policies, procedures, work instructions, and other documents that influence your job.

TABLE IV

Guidelines for Quality and Organizational Change

1. Quality begins with pleasing the customer

2. The quality organization must learn how to listen to customers and help customers identify and articulate their needs.

3. The quality organization leads customers into the future.

4. Flawless, customer-pleasing products and services result from well-planned systems and processes that function flawlessly.

5. In a quality organization, the vision, values, systems, and processes must be consistent with and complementary to each other.

6. Everyone in the quality organization - managers, supervisors, and operators - must work in concert.

7. Teamwork in a quality organization must be based on commitment to the customers and to constant improvement.

8. In a quality organization, everyone must know his or her job.

9. The quality organization uses data and a scientific approach to plan work, solve problems, make decisions, and pursue improvements.

TABLE IV (Cont'd.)

10. The quality organization develops a working partnership with suppliers.

11. The culture of the quality organization supports and nourishes the improvement efforts of every group and individual in the company.

Table V

Strategies for Achieving a Quality Transformation

1. Top managers learn to become leaders, exemplars, and teachers of quality.

2. Managers establish improvement projects that are carefully selected and guided by managers, conducted by cross-divisional teams using the scientific approach, and coached by technical advisors.

3. Top managers engage in quality transformation planning with a two-year blueprint for preparation, start-up, and early expansion.

4. Managers establish processes for the internal coordination, oversight, and technical training and assistance needed to support all quality improvement efforts.

5. Managers undertake specific efforts to change the organization's culture to one more supportive of total quality.

6. Managers receive in-depth education and training for quality leadership development.

CONFIGURATION STATUS ACCOUNTING MADE AFFORDABLE

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May 23, 1990

Approved for Public Release
Distribution Unlimited

The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or the Department of the Navy

Abstract

This paper describes an affordable automated configuration status accounting system that has been developed to meet the needs of the engineering community, the logistics community and the Fleet. Configuration information is vital if the Fleet is to be properly supported. Without complete and accurate configuration information that documents what is installed in the ship, including field changes, engineering changes, ORDALTS and MACHALTS, proper support is not possible.

The information system described in this paper has been installed in over 30 Navy and contractor sites. Results to date have been nothing less than outstanding, with productivity improvements in excess of 500 percent. As budgets get leaner, improvements such as this will become commonplace. We will learn to live within constrained budgets and produce higher quality products. This system is an example of what can be done with emerging technology if properly applied.

LIST OF FIGURES

NOTATIONS

CALS	Computer Aided Logistic Support
CDM	Configuration Data Manager
CSA	Configuration Status Accounting
DOS	Disk Operating System
HSC	Hierarchical Structure Code
LAN	Local Area Network
NSA	Naval Supervising Activity
NPPSO	Navy Publications and Printing Service Office
NSY	Naval Ship Yard
NWS	Naval Weapons Station
RIC	Repairable Identification Code
SAC	Service Application Code
SCLSIS	Ship Configuration and Logistic Support Information System
SEACEN	Naval Sea Support Center
SNAP	Shipboard Non-Tactical ADP Program
SPCC	Ships Parts Control Center
TYCOM	Type Commander
WAN	Wide Area Network
WSF	Weapon Systems File

BACKGROUND

The ability to accurately define the configuration of a ship and its installed systems is a critical factor in obtaining proper shipboard maintenance and logistic support. The Navy's maintenance and logistic support infrastructure must be able to identify accurately and completely what is installed in the ship if the ship is to be effectively supported. Configuration information provides the foundation upon which the maintenance and support structure is built (See Figure 1). To emphasis the importance of accurate configuration information, consider the linkage between configuration information and logistic support elements: The COSAL is driven by configuration information in the Weapon System File (WSF). Technical manual, test equipment and PMS distribution is also based on WSF configuration information.

Because accurate configuration information is so important to the success of most programs, and the quality and

timeliness of data from the Weapon System File (WSF) was less than satisfactory, past Navy managers developed independent configuration information systems that were capable of processing and storing the unique configuration data required to satisfy their specific needs. Each independent system contained a valuable subset of configuration, engineering, and logistics information. However, because of inconsistent data element definitions, inconsistent storage formats, incompatible interface formats and incompatible computer systems (hardware and software), the information was not shared with those outside the program office. There was also the attitude that "My data is correct; however, I'm not so sure about yours." This attitudinal problem also inhibited the sharing and correlation of information.

THE CLOSED LOOP SYSTEM

The Shipboard Non-tactical ADP (SNAP II), a Harris mini-computer programmed in COBAL, provides the ship with configuration and logistics information to support preventive and corrective maintenance. When shipboard hardware or software is changed out, or new equipment added, or existing equipment deleted, the ship utilizes the SNAP system to create a configuration change transaction to let the world know that a change took place (See Figure 2). The transaction flows from the ship, thru the TYCOM ADP system, thru the Central Data Exchange to the CDM. The CDM insures the transaction is complete, reformats it so the SPCC computer can read it and forwards it to SPCC. On a monthly basis, SPCC combines this configuration information with the appropriate Allowance Parts List (APL) information and forwards the combination to NAVMASSO for reformatting and distribution to the ship; closing the loop. The three primary players in this process are; the Ship, the CDM and SPCC.

OBJECTIVE

The objective of the CDM ADP improvement task was to design, develop and test an EFFECTIVE, EFFICIENT and AFFORDABLE informationprocessing system for the CDMs (See Figure 3). In this context effective means: a system that produces complete, accurate and timely transactions. Efficient means: a system that significantly increases thru-put (to accommodate the increased data flow resulting from introduction of SNAP) and, at the same time, decreases the reject rate at the WSF data entry point. Affordable means: the ADP system cost associated with processing a transaction at the CDM must be reduced from approximately $5.00 per transaction to $0.50 per transaction.

It was not the objective of this task to improve SNAP or the WSF portions of the closed loop system.

PROBLEM DEFINITION

In late 1986, an analysis of the situation confronting the existing Configuration Status Accounting (CSA) system confirmed the existence of the problems listed in Figure 4.

Lack of Control and Accountability

First, it was commonplace for a single equipment installation to be separately reported by the ship, the installing activity, and a Configuration Validation Team. To avoid duplicate or triplicate reporting of an installation or field change, SEACEN personnel would remotely access the WSF to conduct database research. This research was time consuming and could be conducted on only 1% of the transactions processed monthly. Even with 100% review, multiple reporting of actions remained a possibility since any activity could submit data directly to the WSF without the consent or knowledge of the SEACENs. The non-reporting of an equipment or field change installation was also quite possible.

Without a complete ship class on-line database, the SEACEN personnel were unable to review all configuration records to ensure that each system, equipment or field change was loaded into the WSF.

Lack of Engineering Involvement

The Program Manager nor the cognizant ISEA were involved with the SEACENs data processing operation. In addition, most ISEAs did not monitor the quality of their information contained in the WSF. If they had conducted such inspections, they would have detected that components of their system were missing, or excess components existed, or perhaps, complete systems were missing from a ship or ship class. It is fair to say that the engineering community did not participate actively in the CSA process.

Lack of Built-In Quality Control

The SEACENs had transaction processing capabilities only; they did not have complete on-line databases for the ships they were responsible for. The SEACENs were locked into flat files, COBAL application programs and ineffective computer networks which obstructed on-line databases from becoming a reality. Lack of anon-line database precluded built-in quality control of the ship class database.

The inherent disadvantage of a transaction processor is that only limited editing can be applied. The incoming

transactions can be inspected for completeness, but assurance could never be made that each component of the system was reported and that the submission did not create a duplicate entry. Although the SEACENs had WSF access to make such assurances, the time required to query the WSF precluded all but the most questionable transactions to be researched.

Increased Volume of Transactions

Prior to SNAP II, the average number of OPNAV 4790/CK transactions processed was approximately 50,000 per year (FY-83). After the SNAP II installations, this number increased significantly to approximately 80,000 per year (FY-88). This represents a 60% increase in the number of configuration transactions that needed to be processed. This increased volume severely stressed the SEACENs ADP processing systems. At that time, the SEACENs were operating a network of terminals tied to a Wang mini-computer, with COBAL application software.

Limited Logistics Information

Although APL information was available in the COSAL, most logistics information was not correlated and presented to the maintenance technician is a usable format. Technical manuals, repair standards, drawings and test requirements information, for example, were not integrated into the COSAL.

Closed Loop System Requires Better Information

Introduction of SNAP highlighted the poor quality of data in the WSF because it made the configuration data visible to the maintenance technician aboard ship, and often prevented the technician from documenting maintenance actions. To document a maintenance action, the sailor must access the SNAP configuration record for the equipment or system upon which maintenance was performed. This requirement means that every maintenance significant system or equipment installed in the ship must have a configuration record in the SNAP database. Also, a configuration record must exist if repair parts support is to be provided.

Lack of a Standard Affordable ADP System

Seven different sets of software were developed in response to the SCLSIS program. They were developed and installed in-house by the CDMs, and were operated on in-house mainframe or mini- computers. One exception to the in-house operation is the mainframe computer located at NARDAC Jacksonville, which is accessed remotely over dedicated phone lines.

CONCEPTUAL SOLUTIONS

To correct the aforementioned problems and accomplish the objective noted above, NAVSEA, in February 1987, established the SCLSIS Program within CEL-TD as the Navy's central authority for integrating ship configuration status accounting (CSA) and logistics information. Building on concepts that had been developed and tested as part of the Expanded Planning Yard program, CEL-TD updated and published a revised SCLSIS Technical Specification, NAVSEA Tech Spec 7070-900A. This Tech Spec contained both the technical requirements for SCLSIS and the business rules that the system must meet.

The creation of the Micro-based Configuration Status Accounting System (Micro-CSA) was developed to meet the requirements of the Tech Spec, and resolve the technical problems noted above.

Control and Accountability

To resolve the problems of multiple data entry, Configuration Data Managers (CDMs) were designated as the singular authority for entering configuration information into the WSF for a ship class. Figure 5 lists the CDMs and the ship classes for which they are responsible.

Engineering Involvement

The engineering community has been asked to develop Class Functional Files for the ships, systems or equipment they are responsible for. The Class Functional File is a hierarchically structured, top-down-breakdown description of a ship class, including its systems and equipment. The Class Functional File is based on the Expanded Ship Work Breakdown Structure (ESWBS) numbering system. The development and ownership of the Class Functional File by the engineering community will overcome the exclusive nature of prior CSA systems, and will provide a much more complete and accurate information system.

Interfaces with Naval Shipyards, SUPSHIPS, private shipyards and Type Commanders (TYCOMs) has been strengthened. Briefings and training sessions were held to familiarize the players with the "Closed Loop System."

Built-in Quality

Quality control is built into the process in several ways. To ensure data quality, the CDM must possess on-line

data for all hulls of the class. Each of the databases must be searchable by several data elements (keys) to facilitate database research, or to address questions posed by the Fleet or fleet support activities.

A search of the complete database for the existence of a record targeted for a change or deletion is required, and now possible, since the CDM possesses a complete on-line database. Also, this capability insures that multiple reporting of a single on-board action has not occurred.

Micro-CSA provides twenty-eight (28) built-in edit features to ensure transactions are error free prior to submission to the WSF.Each transaction is validated against the Repairable Identification Code (RIC) table containing 737,000+ valid codes, the Service Application Code (SAC) containing 24,000+ values, the Equipment Identification Code (EIC), etc. These tables are updated on a monthly basis.

Data quality is also achieved by comparing the class functional file to the ships physical file. The Micro-CSA system compares the quantity reported on the transaction with the quantity allowed in the Class Functional File. The system highlights errors, and will not allow transactions to be added to the database that would cause the quantity to exceed the acceptable range.

Volume

The interactive update capability must be designed to cope with the high volume of incoming data from the ship, and other sites who previously submitted their transactions directly to the WSF. Micro-CSA has the capability to make class-wide assignments to all on-line hulls simultaneously.

In addition, the larger volume installations can be made more efficient by taking advantage of the recent improvements in ADP technology; the 386 and 486 chips, optical drives, Ethernet Local Area Network (LAN), and high capacity disk drives.

Logistics Information

Another feature which distinguishes SCLSIS from prior CSA systems is the requirement for the CDM to research logistic support information associated with a configuration item and create transaction records containing this information. This new information addresses Technical Manuals, Maintenance Index Pages (MIPs), Drawings, Technical Repair Standards (TRSs) and Test Equipment. This compendium of engineering and logistics information is made available to the technician via the SNAP II computer. When the technician selects the equipment from the SNAP configuration file, SNAP will list all engineering and logistic support information in the database. This information will assist the technician accomplish the required maintenance.

Standard Affordable CDM ADP

To make the ADP system affordable, all required functions must be capable of being performing on a standard microcomputer (Zenith Z-248 or equivalent, under MS-DOS operating system. In addition, the application software must be written in a high level language to minimize the development and maintenance cost. To conserve memory, and to build in quality control, the application software design must take advantage of relational database features and query languages. The entire system must be self-contained with its design engineered for desk-top operation. All of the tools for tape input/output, database reconciliation, file reorganization, and security functions must be menu-driven. These features allow a System Administrator to manage individual databases, reference files, security access, and LAN operations without resorting to outside consultation or assistance.Validation Aids

Micro-CSA provides the capability to produce validation aids for those instances where the existence of an equipment remains questionable and an on-site inspection becomes necessary. The system contains a complete Component Characteristics File (CCF) which contains physical attributes which are easily identifiable during an on-site inspection. The CCF file contains information on 2,798,156 RICs.

Database Compare/Synchronization Function

Micro-CSA has a built-in database compare feature that allows the CDM to compare the CDM database with the ship's SNAP database, or the WSF database. The CDM selects the data fields that are to be compared and Micro-CSA prints out a list of records that do not match, or optionally, creates transactions to bring the databases into synchronization.

INDEPENDENT VALIDATION & VERIFICATION

Micro-CSA has undergone Independent Validation & Verification (IV&V) and has been certified by Naval Weapons Station (NWS), Concord. In fact, the system has had each of its last two software releases certified during the past eighteen months. This action was taken to insure that Micro-CSA meets all the SCLSIS technical and business rule requirements.

IMPLEMENTATION

All the aforementioned CDM ADP requirements, and additional features, were easily met thanks to use of a modern relational database language, and sophisticated programming, which reduced software development costs by more than 70% when compared to COBAL software development costs. Micro-CSA has the capability to perform all the functions required of it by the Tech Spec, and more. As its name implies, Micro CSA is a microcomputer based production tool designed to operate as a single work station, or collectively through a network.

INSTALLATION and EVALUATION

Ingalls Shipbuilding

Micro-CSA was installed at Ingalls Shipbuilding in April 1989. Ingalls, as CDM, is responsible for managing thirty-five hulls of the DD-963/DDG-993 Ship Classes. The Ingalls SCLSIS database contains more than one million records, with the number increasing hourly due to research and assignment of new configuration, field change and logistics records. The hardware, software and operations support installed at Ingalls is shown in Figure 6.

Two 386 based microcomputers house the databases which are available to ten Zenith Z-248 microcomputers through a local area network. Two 386 based microcomputers are reserved for analysts tomake class-wide assignments to all thirty-five on-line hulls simultaneously. One 386/microcomputer is placed off-line for RIC research and for CDM database comparisons with the WSF and SNAP II databases. The Components Characteristics File (CCF) which requires 236 megabytes of disk space is housed on an optical drive capable of storing 1.2 gigabytes of information. A desk-top laser printer is available to all users within the network and is capable of printing 8 pages per minute.

Pearl Harbor Naval Shipyard

By contrast, the installation at Pearl Harbor Naval Ship Yard utilizes a Zenith Z-248 microcomputer for management of the ARS-50 Ship Class. A 9-track tape drive subsystem and floppy drive provide the necessary interface for the loading and extraction of databases. A dot-matrix printer is available for small custom reports; large SCLSIS products are output to tape and sent to the local Navy Publication and Printing Service Office (NPPSO) for printing. For a small ship class like the ARS-50, the edit tables and reference files are tailored by the software development team to include only the records applicable to the class. These subsets are accommodated on the smaller disk drive (80 meg) of the Zenith Z-248, thereby allowing Pearl Harbor NSY to fulfill their SCLSIS CDM mission at an equipment cost of approximately $5,000.

Naval Sea Support Center, Pacific

A third Micro-CSA implementation example is the installation at Naval Sea Support Center, Pacific (SEACEN,PAC). SEACEN,PAC is responsible for many ship classes and shore stations of varying sizes. To address this responsibility, SEACEN,PAC has organized into five codes; each assigned one or more ship classes or shore sites. To support the new organization, each code will have a separate Micro-CSA LAN, with a bridge interconnecting all five LANs to a coordination code. The coordination code can monitor the transaction activity for all ships/shore stations. At press time, SEACEN,PAC had installed four LANs containing an ATS-386 and forty Zenith Z-248 microcomputers. A 9-track tape drive subsystem and several printers are available within each LAN. A local NPPSO facility is frequently used for the printing of large SCLSIS products. The installation of high capacity disk drives and distribution of databases throughout the network accommodates the storage of ninety-three (93) ship databases.

One of the greatest strengths of Micro-CSAis its flexibility with regard to hardware. Of the fifteen sites which use the system as a daily production tool, no two sites have identical equipment. As evidenced from the installation descriptions above, the selection of the hardware configuration is not mandated by the system, but rather the user. The CDM decides the specific type and number of equipments in accordance with the number of ships to be managed. A microcomputer outfitted with a 286, 386 or 486 chip operates identically using Micro CSA application software; the only difference being the processing speed. This strength allows flexibility for the NAVSEA offices which fund and oversee each ofthe sites. In many instances, microcomputer hardware and MS-DOS software is available to the Program Manager. This type of situation allows the CDM to be up and running as soon as the WSF databases can be delivered and loaded into his system.

Cost

The cost of an installation varies greatly depending upon the number of ships assigned to the CDM. A greater number means that more disk space, terminals, and print capability are required to meet the program objectives. As mentioned previously, a basic operation such as the one at Pearl Harbor NSY consisting of a Zenith Z-248, tape drive subsystem, and dot-matrix printer costs approximately $5,000, with an expected life of four years.

With regard to a larger installation, let us review the cost of the Micro-CSA system installed at Ingalls Shipbuilding in Pascagoula, MS. The hardware, software and operations costs for four (4) years totals $323,620. This includes the equipment (30%), maintenance contracts (6%), supplies (4%), and operations payroll (60%) to support fifteen full-time CDM personnel for a period of four years. During the four year period, it is expected that the system will be used 120,000 hours (15 people x 2000 hrs/yr x 4 yrs). This number is conservative since additional processing often occurs overnight. The Micro-CSA cost of $2.69 per computer hour includes all possible costs and is therefore comparable to a mainframe terminal charge of $15 to $25 per hour.

Efficiency

The Micro-CSA installation at Ingalls Shipbuilding replaced an in-house developed system which was operating on an IBM 3090 computer outfitted with three 650 MB disk drives and six high-speed printers. From September 1988 to April 1989, this CDM system averaged 9,500 transactions monthly in support of the DD-963 and DDG-993 Ship Classes. Installation of Micro-CSA occurred at Ingalls Shipbuilding in the April/May 1989 time frame. The first submission generated by Micro-CSA at Ingalls Shipbuilding in May 1989 increased production by a factor of 5.5 to 52,000 transactions (See Figure 7). During the following two months, Ingalls generated 101,000 and 35,000 transactions, respectively. Since that time, that number has increased to an average of 193,000 transactions per month, a 2000 percent increase.

ADP Cost per Transaction

The annual cost for the mainframe at Ingalls Shipbuilding was $600,000 which averages to $50,000 monthly. This represents a cost of $5.26 per transaction. Installation of the Micro-CSA system at Ingalls reduced the cost to $0.035 per transaction (See Figure 8).

FUTURE INSTALLATIONS

At the present time, the Micro-CSA system is continuing to enjoy rave reviews as it is being installed at new sites. The following sites are currently scheduled for installation upon delivery of their ADP equipment: Ingalls Shipbuilding for CG-47 Class; Bath Iron Works for DDG-51 Class; U.S. Coast Guard for all USCG hulls and USCG shore stations; SEACENTPAC Code 926 for U.S.Shore Stations; Portsmouth NSY for SSN 671 and SSN 685; and Charleston NSY for SSN 635 (See Figure 9).

SUMMARY

The Micro-CSA system has met or exceeded all expectations. In summary, a comparison of our original objectives with the results achieved at Ingalls shows that effectiveness improved, efficiency improved and cost per transaction decreased dramatically (See Figure 10).

This is an example of what can be done with a clear view of the requirements, an understanding of the possibilities offered by current and emerging technology, and a desire to improve the logistic support system.

P.S. Demonstration

A Micro-CSA demonstration package is available which contains the entire set of certified application software, as well as sample databases from the FFG-7 Class and applicable portions of the reference files. Any SHAPM, SLM or support manager, who would like a system demonstration, can be provided with this package. This demonstration package allows the Program Office or field activity to review and use all the features of the Micro-CSA system prior to making a final decision on which CSA system to use.

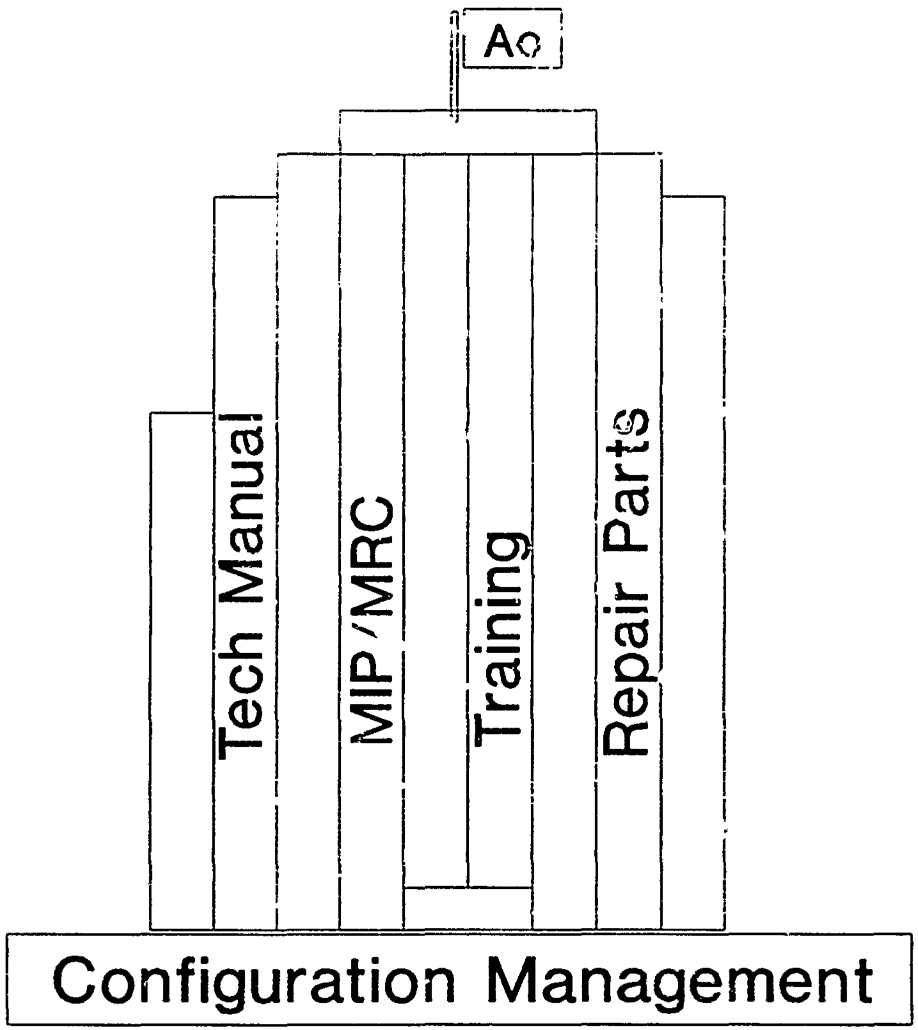

Figure 1 CM - The Foundation for Logistics

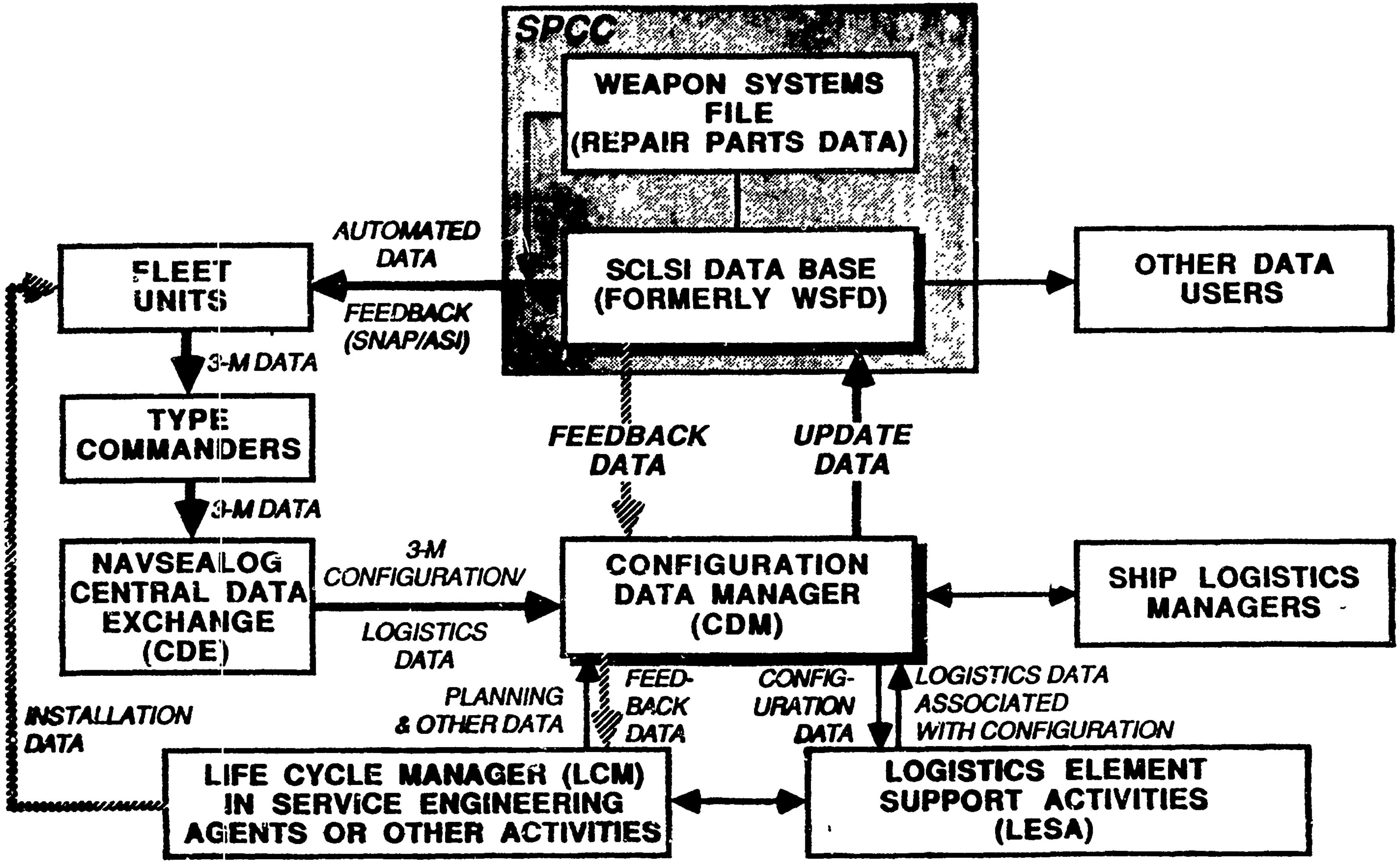

Figure 2 The Closed Loop System

CDM ADP Objectives

- Effective
  - Complete
  - Accurate
  - Timely
- Efficient
  - Increase thru-put
  - Decrease reject rate
- Affordable
  - Significantly reduced processing costs

Figure 3

CSA Problems

1. Multiple inputs to the WSF...Lack of CONTROL and ACCOUNTABILITY
2. Lack of ENGINEERING involvement
3. Lack of BUILT-IN QUALITY control
4. Increased VOLUME of transactions
5. Very limited integration of LOGISTICS INFORMATION
6. Closed Loop System requires more COMPLETE, ACCURATE and TIMELY information
7. Lack of STANDARD AFFORDABLE CDM ADP system

Figure 4

COGNIZANT CDM BY U.S. NAVY SHIP CLASS

NAVAL SEA CENTER, PACIFIC

Assigned Ships:

AE 21	AE 26	AE 32	AFDB	AFDL 1	AFS 1	AGSS 555
AGSS 563	AOE 1	AOR 1	APL 17	ARDM (ALL)	ARS 6	ARS 38
ASR 7	ASR 21	ATF 66	ATS 1	BB 61	CG 26	CG 16
CV 41	CV 62	CV 64	CVN 68 (PAC SHIPS ONLY)		FF 1037	FF 1040
FF 1052	FF 1098	FFG 1	SS (ALL)	MSO 422	MSO 423	MSO 428
MSO 508	TC 841	TWR (ALL)				

NAVAL SEA CENTER, ATLANTIC

Assigned Ships:

AD 14	AD 37	AD 41	AGDS 2	AGF	AS 11	AS 19
AS 31	AS 33	AS 36	AS 39	AR 5	AO 51	AVT 16
CGN 9	CGN 25	CGN 36	CV 43	CV 59	CV 60	CV 63
CV 66	CVN 68 (LANT SHIPS ONLY)		DD 946	DDG 2	DDG 37	LCC 19
LCU 1473	LCU 1610	LPD 1	LPD 4	LPD 7	LPD 14	LPH 2
LPH 9	LKA 113	LSD 28	LSD 36	LST 1179	SSN 594	SSN 597
SSN 608						

BATH IRON WORKS

Assigned Ship Class: DDG 51

CHARLESTON NAVAL SHIPYARD

Assigned Ship Classes: ARL 24, MCM 1

GENERAL DYNAMICS

Assigned Ship Class: SSBN 726

INGALLS SHIP DIVISION

Assigned Ship Classes: CG 47, DD 963, DDG 993

LONG BEACH NAVAL SHIPYARD

Assigned Ship Class: FFG 7

Figure 5

NEWPORT NEWS SHIPBUILDING AND DRYDOCK CO.

Assigned Ship Class: SSN 688

NORFOLK NAVAL SHIPYARD

Assigned Ship Classes: CGN 38, CVN 68, LHA 1, LHD 1

PEARL HARBOR NAVAL SHIPYARD

Assigned Ship Class: ARS 50

PORTSMOUTH NAVAL SHIPYARD

Assigned Ship Classes: SSN 637, SSN 671, SSN 685

PUGET SOUND NAVAL SHIPYARD

Assigned Ship Classes: AO 177, AOE 6, CVN 65, CV 61

SUPERVISOR OF SHIPBUILDING, BOSTON USN

Assigned Ship Classes: LSD 41, LCAC

SUPERVISOR OF SHIPBUILDING, JACKSONVILLE USN

Assigned Ship Class: PHM 1

VITRO CORPORATION

Assigned Ship Classes: SSBN 616, SSBN 627, SSBN 640

Figure 5 (Cont)

DD963/DDG993
SCLSIS PROCESSING

MICRO CSA
15 USERS MANAGING 35 HULLS
4 YEAR EQUIPMENT & DATA OPERATIONS COST

DD963/DDG993
SCLSIS PROCESSING

5 386 MICROS — $48,745
- o 300 MB HARD DRIVE
- o 20 MHZ
- o 1 MB RAM
- o COLOR MONITOR
- o 1 YEAR WARRANTY
- o 3 YEAR MAINTENANCE CONTRACT

10 286 MICROS — $38,800
- o 80 MB HARD DRIVE
- o 640 K RAM
- o COLOR MONITOR
- o 1 YEAR WARRANTY
- o 3 YEAR MAINTENANCE CONTRACT

SUPPLIES: — $12,800 ($3,200/Year)
- o PRINT CARTRIDGES
- o RIBBONS
- o TONER
- o PAPER
- o MAGNETIC TAPES
- o DISKETTES
- o CLEANERS/DEMAGNETIZERS

DATA OPERATIONS: — $194,000 ($48,500/Year)
- o ARCHIVING
- o DATA LOADING/EXTRACT
- o SYSTEM ADMINISTRATOR FUNCTIONS
- o FILE REORGANIZATION
- o REPORT GENERATION (HIGH VOLUME)

2 TAPE DRIVE SUBSYSTEM — $10,200
- o 9 TRACK
- o 1600/3200/6250 BPI
- o CONTROLLER BOARD
- o UTILITY SOFTWARE
- o 4 YEAR MAINTENANCE CONTRACT

1 LAZER PRINTER — $4,325
- o 8 PAGES PER MINUTE
- o 3 YEAR MAINTENANCE CONTRACT
- o 1 YEAR WARRANTY

8 DOT MATRIX PRINTERS — $6,500
- o 1 YEAR WARRANTY

15 TWISTED PAIR LAN BOARDS — $8,250
- o LAN SOFTWARE
- o WIRING
- o TAP BOXES

TOTAL COST FOR EQUIPMENT = $323,620 & DATA OPERATIONS

TOTAL HOURS OF EQUIPMENT USAGE = 120,000 HOURS (4 YEARS WITH 15 USERS)

TOTAL COST PER COMPUTER HOUR = $ 2.69/HOUR

Figure 6 System Hardware/Software

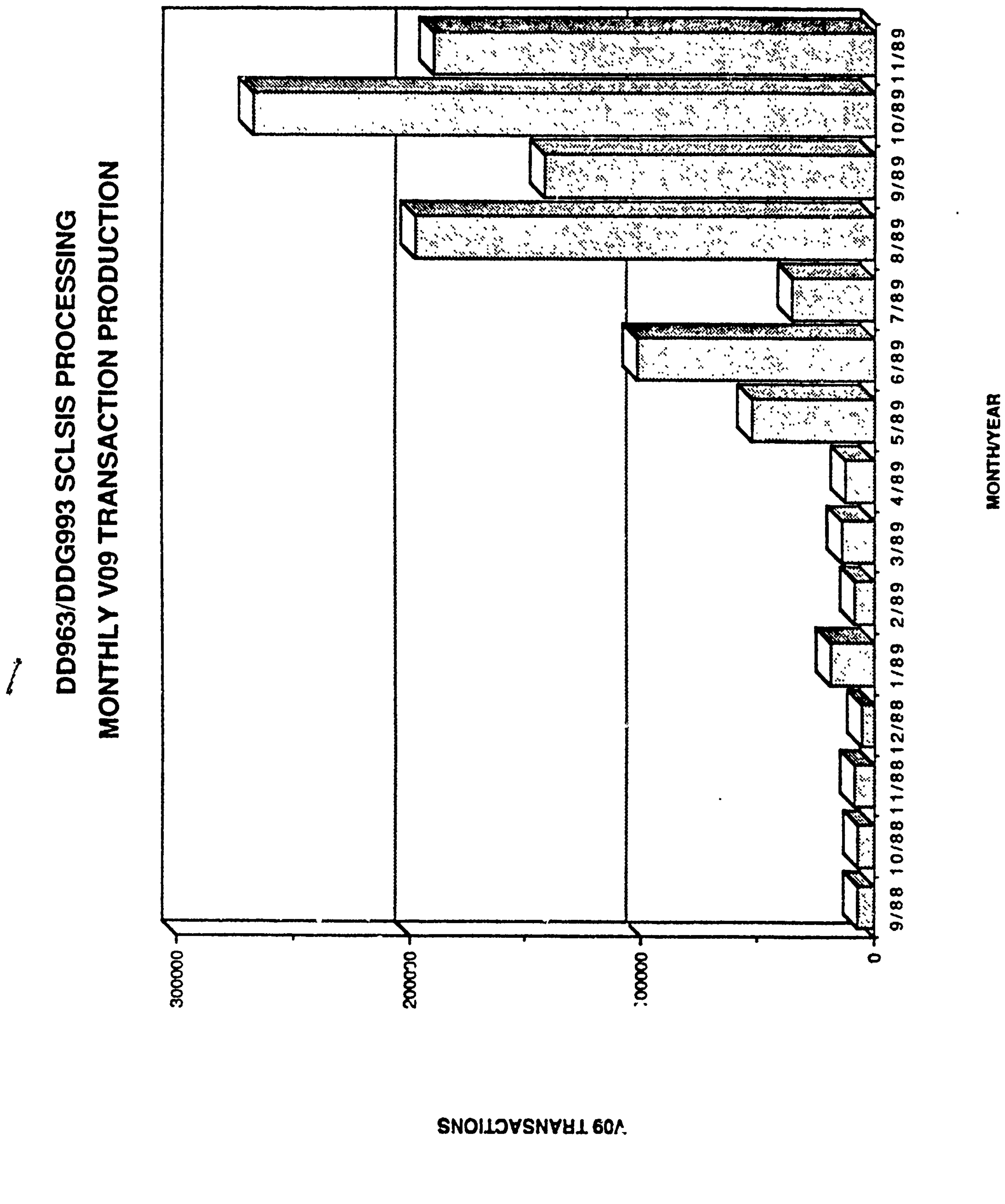

Figure 7 Efficiency Improvement

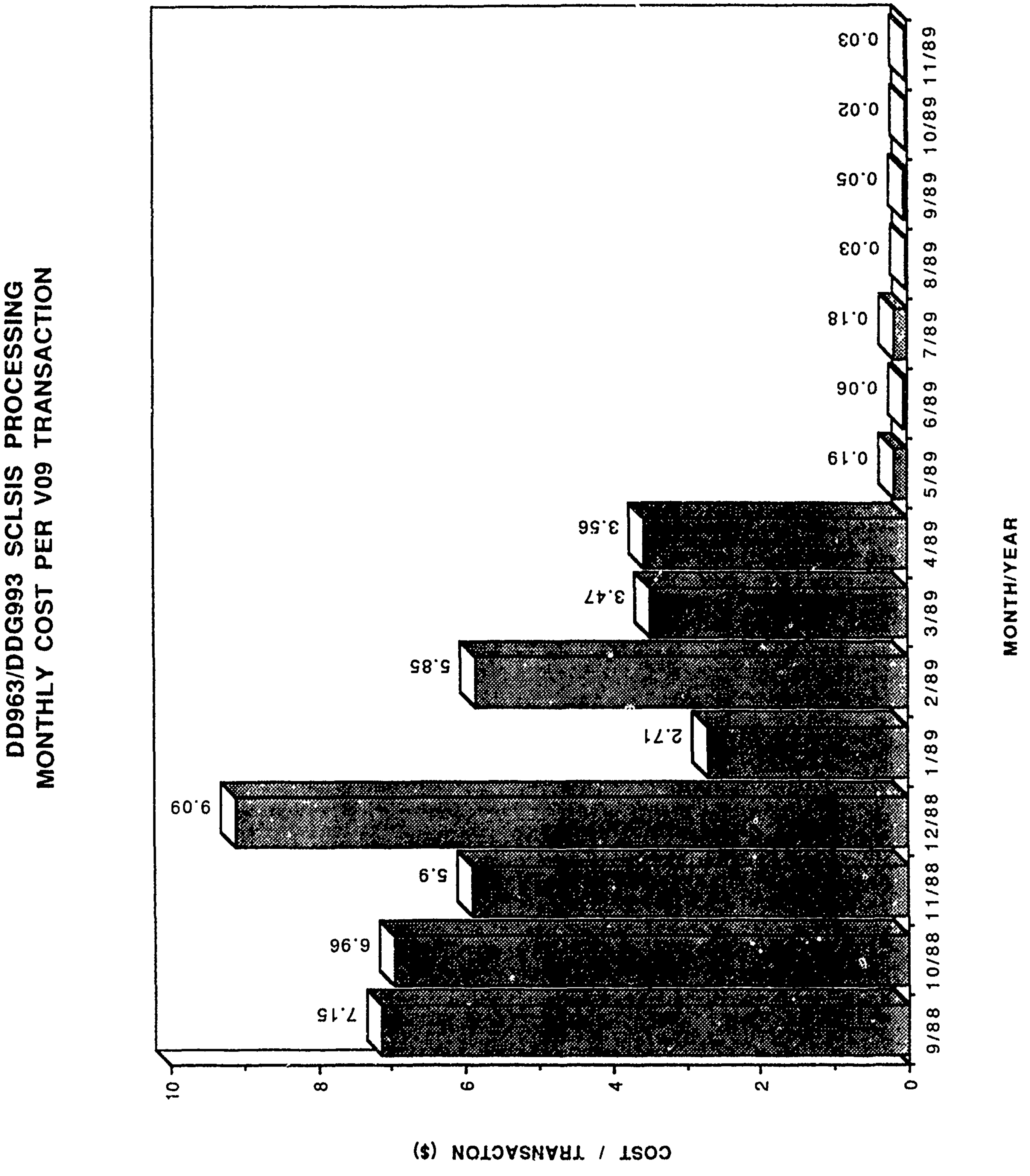

Figure 8 Affordability Improvement

MICRO CSA SITES

MANAGING
USN & USCG SHIPCLASSES,
& USN SHORE STATIONS

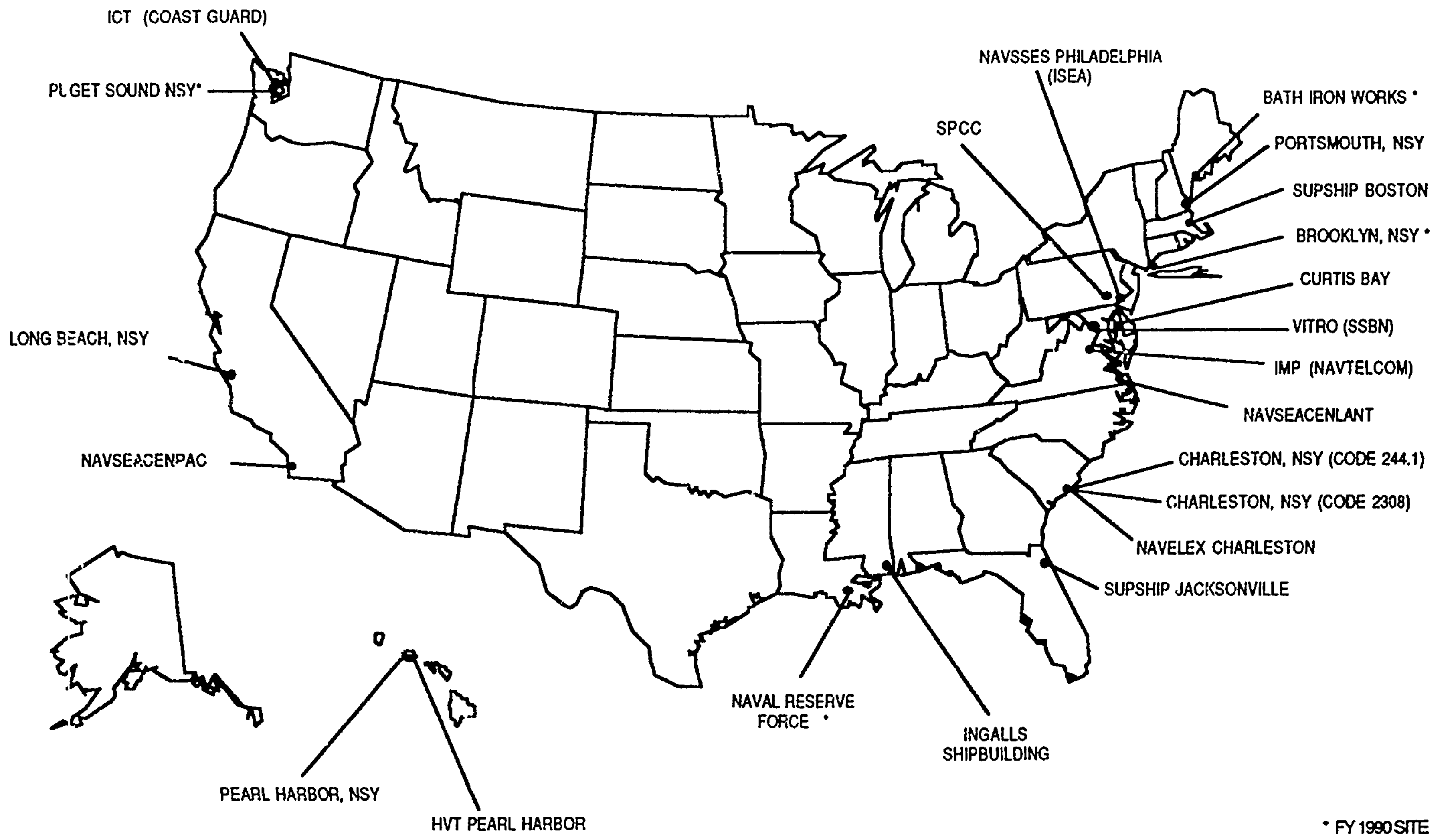

Figure 9 Current and Future Sites

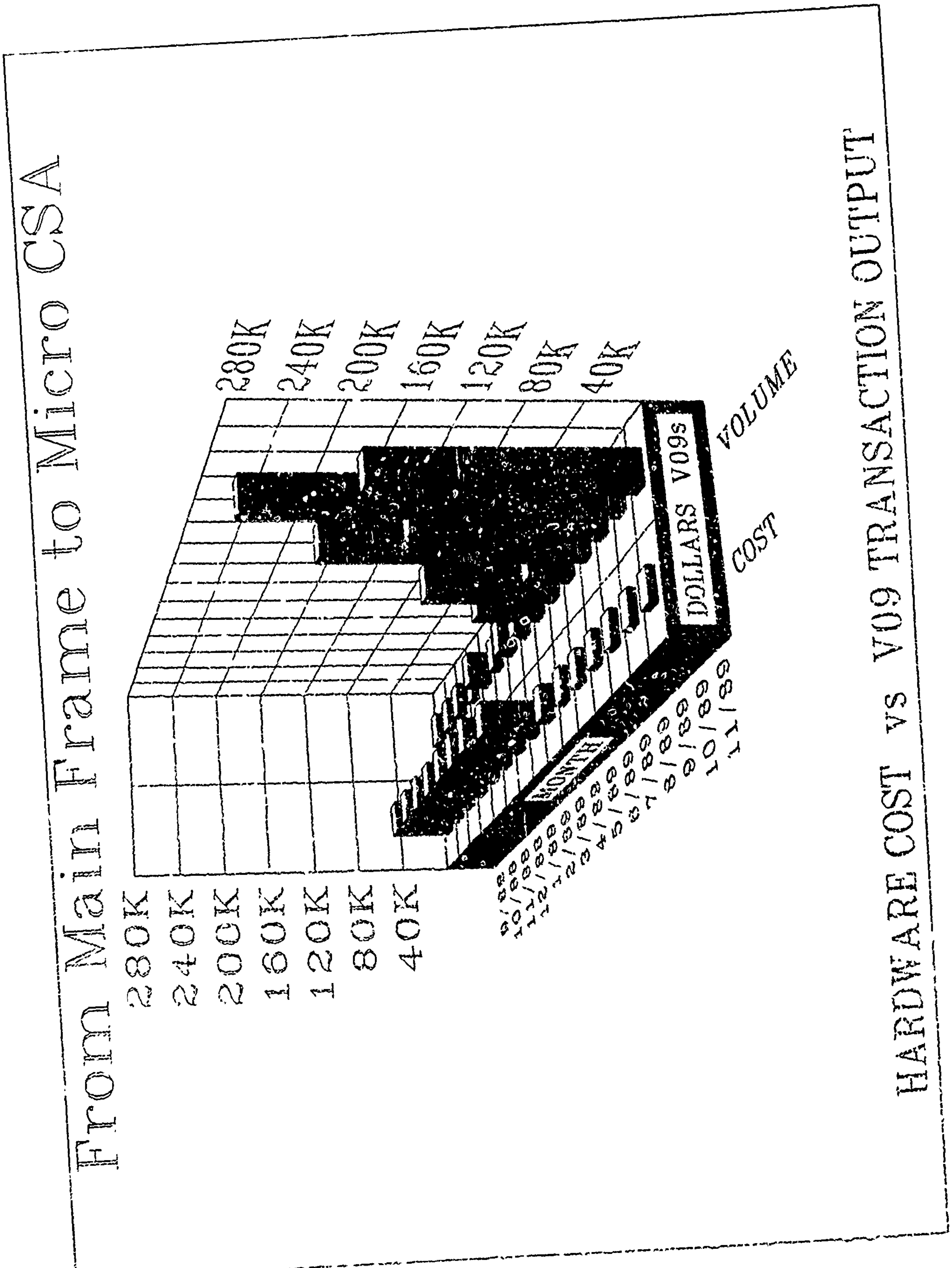

Figure 10 Summary

U.S. NAVY SURFACE SHIPS PERFORMANCE AND SPECIAL TRIALS - WHY?

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March 1990

The views expressed herein are the personal opinions of the authors and are not necessarily the official views of the Department of Defense or of the Department of the Navy.

ABSTRACT

Performance and Special Trials (P&ST) are conducted aboard the lead ship of a new class by the Naval Sea Systems Command (NAVSEA) following the ships' post delivery shakedown period. The P&STs are coordinated by NAVSEA Code 56X1 and performed by David Taylor Re-search Center (DTRC) and Naval Ships Systems Engineering Station (NAVSSES). The NAVSEAINST 9094.5 establishes the policy requiring these trials. The data obtained from the P&ST is used to:

- define the ship class baseline performance characteristics, operating capabilities and limitations
- provide ships' command with the performance data to operate his ship safely and more efficiently thereby reducing life cycle costs
- correlate trial results data with the model test data
- establish the baseline for future ship design of a similar class
- allow the naval planners and designers to assess the accuracy of the design performance predictions and design procedures

Several problems have been associated with the implementation of a total Performance and Special Trials plan which has decreased the number of P&ST tests conducted. Problems which may be listed are; the lack of judicious planning, budget restraints imposed by Gramm-Ruddman-Hollings law, increases in costs to conduct these trials and lack of awareness of the necessity of these tests and trials. In addition, the current trend to include more requirements in the ship construction specifications causes duplicate efforts thus increase ship construction cost. Also, occasionally the trial agenda was not completed due to ship schedule changes, insufficient fuel allocation, inclement weather, etc.

The purpose of this paper is two fold: first, it provides discussions on each of the specific P&ST tests which will enhance awareness; second, it provides suggestions and initiatives to improve the implementation of P&STs.

Since joining NAVSEA, both authors have been involved with implementation of the P&ST and have become aware of many opportunities to improve the implementation of these trials by judicious planning, coordinating, conducting, and controlling cost.

LIST OF FIGURES

ACRONYMS

AT	- Acceptance Trials
BT	- Builder Trials
CNO	- Chief of Naval Operation
CPP	- Controllable Pitch Propeller
DTRC	- David Taylor Research Center
EIT	- Engineer-in-Training
NAVSEA	- Naval Sea Systems Command
NAVSSES	- Naval Ship Systems Engineering Station
P&ST	- Performance and Special Trials

PC	- Program Control
POA&M	- Plan of Action and Milestone
RPM	- Shaft Revolution Per Minute
SDM	- Ship Design Manager
SHAPM	- Ship Acquisition Manager
SHP	- Shaft Horsepower
SLM	- Ship Logistics Manager
SNAME	- Society of Naval Architects and Marine Engineers
SS3	- Sea State 3
TYCOM	- Type Command

INTRODUCTION

The NAVSEA Instruction 9094.5 [1] established policy on Performance and Special Trials (P&ST) to be conducted by NAVSEA aboard the lead ship of a new class after delivery to the Navy. The instruction assigns the Propulsion Systems Analysis Division (56X1) to coordinate the planning and implementation of these trials with Ship Acquisition Manager (SHAPM), Ship Logistics Manager (SLM), and other NAVSEA technical codes. These trials are also conducted aboard ships that have undergone major conversions, or ships in which new equipment is installed that affects propulsion and maneuvering capabilities.

The P&STs, as per references [1], [2] and [5], are categorized in the following four groups:

HYDRODYNAMIC PERFORMANCE TRIALS:

(1)Standardization (SPEED vs RPM/SHP/TORQUE/THRUST)

(2)Acceleration and Deceleration

(3)Tactical Trials

(4)Maneuvering Trials: Zig-Zags (Horizontal Overshoots), Spirals Lateral Stability) and Low Speed Controllability

(5)Seakeeping and Seaworthiness

MACHINERY PERFORMANCE TRIALS

(1)Fuel Economy

(2)Trail Shaft and Locked Shaft

HULL AND PROPULSION VIBRATION

SPECIAL TRIALS

Conducting thorough trials impacts elsewhere, not only defining the characteristics of a particular ship, but also defines the characteristics of the particular hull form. Correlating trial data and model test data identifies and verifies factors, allowances, and procedures which can reduce the design effort, required time and allow more accurate design performance predictions in future ship designs with a similar hull form.

The first part of the paper provides a brief discussion for each trial along with sample illustrations to provide the reader comprehensive refresher material.

The second part of the paper continues with discussions on the problems encountered and improvements that can be achieved in the implementation of these trials. The conclusion summarizes and provides the suggestions that could benefit the Navy by providing better ship performance trials and improved capability for future ship designs with more efficient and safe fleet operations.

OVERVIEW OF PERFORMANCE AND SPECIAL TRIALS

The discussions of some of the trials were excerpted from DTRC correspondence on ship trials and references [1] through [8]. This correspondence, untitled and unnumbered, was a valuable source of information.

HYDRODYNAMIC PERFORMANCE TRIALS

(1) Standardization Trials

Standardization Trials are part of the tests that determine the overall Hydrodynamic Performance of the ship. As shown in figure 1, the baseline relationships between Ship Speed (KNOTS), RPM, TORQUE, SHP (calculated from RPM and TORQUE), and THRUST are established as a result of Standardization Trials. These trials are conducted to determine the calm water performance throughout the ships' speed range. Typically six to nine discreet speeds are required to adequately define the speed power curve.

For conventionally powered ships, the trials are conducted at two displacements, design full load and at least 10% lighter (usually normal or light ship) and as close to design trim as possible. The measured data at two displacements shows how changes in displacement affect ship speed and powering. This data allows for the interpolation of speed and powering characteristics over a range of displacements and aids in the direct correlation with the model data. It also provides a basis to establish full power trial requirements for inclusion in the OPNAVINST 9094.1A.

Standardization trials consist of a minimum of three consecutive runs over a radar or acoustic tracking range, alternating in direction, at nearly the same rpm as possible for each speed. This reduces the effects of wind and current on the data. Speed increments of approximately 3 knot intervals are used from speeds of 8 knots to full power or as specified in the trial agenda.

Standardization Trials on ship's equipped with Controllable Pitch Propeller (CPP) systems are normally conducted in both the Program Control(PC) mode and in manual mode. The PC mode is an automatic system which, below certain ship speeds, selects predetermined combinations of propeller pitch and shaft speed in response to the ship speed requested. Standardization Trials in the PC mode are typically followed by a series of runs with propellers over-pitched as well as under-pitched (manual mode). Trials on twin screw ships equipped with CPP systems require that both shaft speed and propeller pitch be equal to develop the same power. With this data, a family of standardization curves depicting speed, power, torque, thrust, and RPM is thereby generated to define the full range of performance characteristics of a given propeller.

The data is used to establish baseline performance characteristics for the entire class. This creates a basis for comparison with effects of hull/propeller fouling and future modifications to ships of the class. This also allows the Navy to monitor future overhaul results by comparison with the baseline data. It also enables Naval Architects and Hydrodynamicists to correlate trial data against model test data and apply lessons learned to future ship designs. One other significant use of the data is to establish requirements for full power and economy trials to be included in OPNAVINST 9094.1A.

This data is also used to establish baseline fuel consumption curves (i.e., Gal/Hour and Gal/Nautical Mile versus Ship Speed, SHP and RPM curves) for various propulsion plant configurations.

(2) Acceleration and Deceleration Trials

Acceleration and deceleration trials are conducted to obtain the rate of acceleration and deceleration under various initial and terminal conditions. One major condition tested is accelerating the ship from dead-in-the-water to the maximum speed available using ahead flank engine order. This determines the maximum practical rate of acceleration which would be governed by the maximum allowable pressure drop in the steam line of a steam ship, or the torque limit curve of a diesel or gas turbine engine. Deceleration conditions may vary for different classes of ships. The ship may be operated in a range of approach speeds at a steady "steaming" condition, decelerating down to dead-in-the-water with engines in full reverse.

These trials are vital in determining the ships maneuvering capabilities and limitations when operating in restricted waterways. To conduct these trials, radar or acoustic tracking is required to obtain the ship's position versus time. From this data, as shown in figures 2 and 3, instantaneous ship's speed, reach and transverse distance can be determined. In ships so equipped, propulsion units are placed in an automatic mode.

(3) Tactical Trials

Tactical Trials are conducted during Performance and Special Trials will consist of operational procedures to determine ship turning characteristics (advance, transfer, and tactical diameter) relative to normal turning circles (figure 4). Ship turning characteristics deter mined from conducting several tactical circles are identified in figure 5.

The Tactical Trials are conducted with as close to a full-load displacement and design trim as practical. The shore-based instrumentation consists of radar or acoustic tracking equipment. Periodic data is obtained to define the coordinates of the turning path at regular time intervals.

The data obtained from these trials indicates any turning irregularities. Reduced turning capabilities indicate possible rudder breakdown and typically occur at higher speeds and rudder angles. Asymmetric turning characteristics when using both left and right rudder angles may also be evident during these trials.

The Tactical Trials data provides valuable information for navigating in a congested areas. Ship's command obtains first hand knowledge of the ships capabilities and limitations with respect to distance and time required for advance, transfer and finally completion of a 360 degree turn.

These trials allow the Navy to create a database and establish the criteria for the entire class. The results will benefit the ship designers since, with the model test results, it verifies rudder performance predictions which will provide a basis for future ship designs.

(4) Maneuvering Trials

The Maneuvering Trials consist mainly of Spirals (Lateral Stability), Horizontal Overshoot (Zig-Zag Maneuvers), and Low Speed Controllability maneuvers. These trials are generally conducted free route with no tracking required from shore stations.

Spiral Maneuvers are designed to determine the directional stability characteristics of a ship [4]. These maneuvers allow evaluation of the ship's ability to resume its original course after being subject to a disturbance, such as a large wave, without the intervention of the helmsman. Spiral maneuvers are usually conducted at a minimum of two forward speeds. The data obtained is steady rate of change of heading as a function of rudder angle. This data is used to determine the response characteristics of a ship to disturbances and also indicate the neutral rudder angle necessary to maintain a straight course. The parameters measured show differences between stable (figure 6) and unstable (figure 7) regions where rudder angle needs to be adjusted. In figure 7, the pronounced hysteresis indicates that this ship is laterally unstable at the speed this test was conducted. For this ship, two to five degrees of right rudder is required to maintain a steady straight line course at the this speed.

Zig-Zag Maneuvers are conducted to determine control characteristics of a ship, in particular the ability of the ship's rudder to control the ship [4]. These maneuvers are generally conducted at two speeds (usually the same speeds as the Spirals) and at a minimum of two rudder angles. For each speed and rudder angle, two runs of alternating rudder angles are sequenced. Figure 8 shows the parameters measured for the Zig-Zag maneuvers. The parameters measured for these maneuvers are the time required to return to the original course once corrective rudder is applied and the overshoot angle. The first parameter determines the ability of a ship to rapidly change course which improves with increased rudder effectiveness. The second parameter provides countermaneuvering ability and is indicative of the amount of anticipation required by the helmsman when operating in restricted waters.

Low-Speed Controllability Maneuvers are conducted to determine the lowest speed at which the ship does not respond to the helm.

Though these three tests are the major part of the maneuvering trials, there are other tests which may be conducted at the discretion of COMNAVSEA [5]. These extra test and trials include:

Free rudder tests, Low-speed rudder response tests, and Steering comparisons (rough weather).

(5) Seakeeping and Seaworthiness

Seakeeping trials are essential to define the mission performance capability of the ships in seas that will be encountered during the life of the ship. Seakeeping trials are particularly important for combatants since their mission has to be accomplished with minimal performance degradation in a seaway. The ship with the better seakeeping ability has a greater combat capability, especially in northern operational areas during winter.

In order for a ship to maintain speed in a seaway it must meet acceptable requirements to minimize slamming, shipping green water and spray. Minimizing ship motions is important so that the crew is able to perform their various tasks.

Seakeeping Trials consist of a series of trials performed in seas ranging from fully sheltered, calm seas, to open seas with high waves and wind. The first and second set of trials (fully sheltered and calm seas respectively) are performed during P&ST and require sea conditions which permit scheduling. The open sea portion of the seakeeping trials recognize the impossibility of scheduling heavy seas at convenient times. Accordingly, this third element of the seakeeping trials represents long term collection of seakeeping data by the ship. This data collection is accomplished by the ship's crew with a ship motion recorder once the ship is in normal service [6].

These trials which determine the actual rather than the predicted ship seakeeping performance need to be conducted in sea states three (SS3) or higher to determine the relative motions of the vessel in rough seas (actual sea state is dependent upon the size of the ship being tested). This element of the results is used in the design of future ships. The second and perhaps most important area where the results of these trials is put to use is that the task/mission performance limiting criteria is used to provide the ship operator with displays (figure 9) which clearly delineate areas of speed and courses where particular ship motions may cause tasks/missions to be dangerous [6].

MACHINERY PERFORMANCE TRIALS

(1) Fuel Economy Trials

The primary purpose of the fuel economy trials is to provide data for three general requirements. First, to serve as a basis of comparison to the design heat balances (for steam ships) or other design point required by the specifications including different operating modes (multiple shafts driving and one or more shafts trailed or locked). Second, to provide data for the preparation of OPNAVINST 9094.1A (29 May 1986) "Full Power and Economy Trial Requirements" for the new class of ships. Finally, to provide data for the "as run" and trial computation of actual cruising radius over a range of speeds [7].

To demonstrate the usefulness of the fuel consumption data, figure 10 is provided as an example. The bottom curves show Gal/Hr vs RPM. Curves on the top show

economical speeds (Gal/N. Mile) for various plant configurations. The lowest points on these bathtub like curves are the most economical speed at that plant configuration. This allows the ship's force to determine what speed requires the least amount of fuel to transit between two points. Conversely, they can estimate how much fuel is needed to transit at a certain speed to meet a required schedule.

For these trials to be useful, the machinery plant must be set as close as practicable to design operating conditions. That is, selection of operating machinery, auxiliary equipment loads, etc., should be as specified or shown in the heat balances or operating guides. These trials should be conducted in free route. During these trials, radical rudder movements should be avoided. Such maneuvers will affect SHP and RPM readings. For the same reason, these trials should be conducted at a time when sea conditions do not exceed SS3. Displacement of the ship during these trials should be as close to full load as practical.

These trials are usually conducted concurrently with the standardization trials in order to correlate speed and powering data with fuel consumption data.

As with the standardization trials, the measured baseline fuel consumption data will be used to monitor future overhaul results by comparison with the baseline.

(2) Trailed and Locked Shaft Trials

The purpose of trailed and locked shaft trials, conducted on multi-shaft propulsion systems, is to determine the limiting shaft RPM values for the driving plant, without exceeding shaft torque restriction and the available ship speed. these values are then used for all ships of the class when operating under either of these conditions. On steam ships, the temperatures, especially those of the trailed /locked shaft turbine stage, cross-over, and exhaust trunk, will be monitored to avoid exceeding manufactures limits. The trials are conducted with the locked shaft trial first and followed by the trail shaft trial for the same shaft.

HULL AND PROPULSION VIBRATION

The objectives of the underway vibration trials are to measure and evaluate the vibration characteristics of the hull, superstructure, masts, and propulsion system. These are instrumented to measure acceleration, velocity, displacement, and alternating thrust and torque during trials. The longitudinal, torsional, and lateral natural frequencies and response amplitudes of the shafting system will be determined for all operating conditions of the propulsion plant and correlated with mathematical analysis. In addition, significant lc ngitudinal, vertical, and athwartships hull natural frequencies and response amplitudes will be determined and reported throughout the operating speed range, including node shape of the hull for each natural frequency.

Vibration measurements are taken in free route and concurrent with other trials as appropriate. Certain vibration measurements may be taken during standardization and tactical trials, but this in no way should preclude conducting additional runs to obtain specific vibration data not otherwise run as part of other trials.

SPECIAL TRIALS

Special Trials are a series of unique trials carried out concurrently with Performance Trials to investigate a particular or unusual aspect of a given ship [3], [5]. These trials are also conducted aboard certain special mission ships, as deemed necessary by COMNAVSEA. Such trials may be needed for experimental purposes or may be dictated by special characteristics of the ship. Examples: the DDG 51 class P&ST includes Underwater Photographic tests to asses the effect of Prairie/Masker; the MCM 1 class required to conduct towed array trials to determine maximum speed and turning characteristics of the ship when towing the array.

IMPLEMENTATION OF P&ST

COORDINATION of TRIALS

In order to provide a central authority on P&ST, the NAVSEAINST 9094.5 should require 56X1 to provide a Liaison Officer who would coordinate the trials between the ship and the third party conducting the trials. The Liaison Officer will provide the proper communication link and assure that the entire trial agenda is completed. The Liaison Officer can assist in explaining how the acquired data will aid the ship's command in the performance of their mission and will provide optimum efficiency and safety.

A review of past trial reports indicates that, occasionally there was insufficient time to complete the trial agenda due to ship's schedule changes, insufficient fuel allocation, inclement weather, etc.

In order to improve the trial crews' ability to conduct all the tests listed in the agenda, the Trial Liaison Officer would have the CNO Project Order. This order requires the Type Command (TYCOM) to incorporate the trials in the ship's operating plan. The benefits of having a NAVSEA Liaison Officer are as follows:

- Assures that all trials are conducted as planned.

- Provides communication link between ship command and trial crew.
- Briefs ship's command about the importance of accurate data for the future ship designs.
- Emphasizes to ship command the necessity of the data to establish baseline performance curves which can be applied to operate the ship safely and more efficiently.
- Solicits help from the crew to take data thus make them feel like they are part of the trial team.
- Provides preliminary fuel consumption curves and ship speed vs rpm, shaft horsepower curves before leaving the ship so that the data can be used immediately.

NAVSEAINST 9094.5

The NAVSEA instruction, NAVSEAINST 9094.5 [1], was prepared in 1985 to establish NAVSEA policies for the implementation of the P&ST. This instruction should be modified to avoid any policy misunderstandings. Certain paragraphs in the "Background" section have been taken out of context and used as if it is policy. The paragraph in question states:

"Decisions regarding the conduct of performance trials have been left to the individual Ship Acquisition Program Managers (SHAPMs) or Ship Logistics Managers (SLMs). The performance trials have not always been conducted on a ship of a new class because a ship or funds or both were not available. Lack of a definite policy regarding performance trials has also contributed to this problem."

It was observed that this paragraph has been used as policy and numerous tests may not have been conducted as a result. It is suggested that the "Background" section be revised to avoid the misinterpretations.

To enhance awareness of P&ST policy, and thus allow better planning, it is suggested that a NAVSEA Performance and Special Trials Guidance Manual be developed. In addition, the following documents should be revised to incorporate the NAVSEAINST 9094.5 as a reference: (1) General Specifications of Ships of the US Navy; (2) Top Level Requirements; and (3) Ship Contract Specifications.

While these trials are called "Performance and Special Trials" in the General Specifications and References [2] and [5], in NAVSEAINST 9094.5 [1] they are called "Performance Trials". The title used in NAVSEAINST 9094.5 [1] should therefore be revised to include the same title as above documents to avoid confusion.

P&ST GUIDANCE MANUAL

The Performance and Special Trials Guidance Manual would include step-by-step guidelines to plan and conduct these trials. This manual would be similar to "Code for Sea Trials" prepared by The Society of Naval Architects and Marine Engineers (SNAME) Technical and Research Code C2 [8]. The Code for Sea Trials (C2) was developed for commercial ships. A P&ST manual will provide a standard guide for the procedures used aboard Naval ships with different missions, thus allowing the utilization of lessons learned from the past experience. Also, as C2 was last published in 1973 and many improvements in trial instrumentations have since occurred these improvements would be included in the proposed NAVSEA manual.

PLANNING

Figure 11 shows the major events of the overall P&ST program. If followed judiciously, the implementation of the total P&ST should be accomplished without restraints in the overall budget for the new class. Particularly since the P&ST cost is a small fraction of the total new class cost and it is only performed on one ship. Major events of the various phases of ship design and construction through which P&ST planning occurs are discussed below:

(1) Contract Design Period

During the contract design phase, the propulsion systems task leader (56X1) must initiate development of a generic P&ST plan and budgetary cost estimate for the SDM and SHAPM. This cost estimate will be prepared by DTRC and NAVSSES based on a work request letter prepared by SEA 56X1. The SHAPM then allocates sufficient funds for these trials.

Also, a Plan of Action and Milestone (POA&M) would be prepared by 56X1 for the P&ST tests to include the events listed below. This POA&M should be carried out through the shipbuilding program stages.

The Trial Liaison Officer (56X1) should ascertain that there are no requirements in the ship specification that would require the shipbuilder to conduct some of these P&ST tests (i.e., Tactical and Maneuvering) during Builders Trials (BT). The data obtained by shipbuilder is subject to many interpretations and adjustments by DTRC because shipbuilder would use different kind instruments than DTRC uses. Also, the accuracy of the data obtained would be questionable since during BT

many tests are being performed and many things may go wrong.

(2) Ship Detail Design Period

During detail design, 56X1 would initiate a revised cost estimate by DTRC or NAVSSES to adjust the budget for these trials and keep all responsible parties aware of the P&ST.

(3) Ship Construction Period

During the ship construction stage, NAVSEA would provide funding to DTRC to accomplish following tasks:

- Procure Thrustmeters, Fuelmeters, Torsionmeters and other equipment necessary to conduct the trials.
- Develop a detailed trial agenda. Again, a more refined cost estimate for each trial event including the schedule of events should bInstall trial equipment (Thrustmeters, Fuelmeters, Torsionmeters etc.) just prior to Builders and Acceptance Trials.

(4) At Sea Period

Prior to or during shakedown period, special temporary instrumentations should be installed by DTRC and NAVSSES. After shakedown period, when the ship is in the possession of the Navy, the P&ST trials will be conducted.

(5) Data Analysis and Reports

The final event of the P&ST program would be the analysis of the trial data and the preparation of reports by DTRC and NAVSSES. These reports will be delivered to the 56X1 Trial Liaison Officer who, after review and comment will forward them to the appropriate SDM, Tech Codes and PMS acquisition code. The PMS code would coordinate the dissemination of these reports to appropriate agencies and the applicable ships.

COST CONTROL

Cost for P&ST is a small fraction of the overall class program cost because only one ship has to be tested to establish baseline performance data for the entire class. In spite of this small cost, recent new ship classes received only a small portion of the required P&ST data due to lack of funding. One reason the number of required trials have been reduced lately is the high cost associated with performing these trials.

There are several initiatives to control cost. These initiatives are as follows:

- Detailed planning to conduct certain tests simultaneously.
- Use of ship's crew for taking the data. Past experience shows that the ship's crew can take accurate data. This also gives ship personnel added incentive to be part of the trial.
- Establish a NAVSEA Trials Branch. Their responsibilities would include procuring and installing trials equipment, providing trial crew to take data, and writing and distributing reports.
- In order to eliminate the duplicate efforts (planning, preparation, installing and removal), the special trial instrumentation provided for Builders Trials (BT) and Acceptance Trials (AT) can be used if P&STs are conducted right after AT. Currently, the P&STs are conducted after ship is delivered which is more than a year after the AT. The trial instrumentation installed for BT and AT are therefore removed from the ship at conclusion of AT as required by ship spec.

CONCLUSIONS

We can conclude by summarizing what has previously been discussed. On recent ship classes only some of the Performance and Special Trials have been conducted. It is our goal that all of the P&ST tests be conducted and data obtained as required by NAVSEAINST 9094.5. In this paper we have discussed what the specific P&STs are and the many opportunities to improve the implementation of them.

These opportunities are summarized below and are suggested for consideration for the future P&STs Program:

- Eliminate any requirements from the ship specifications that would require the shipbuilder to conduct some of the Performance and Special Trials during Builders Trials (i.e., Tactical Circles and Zig-Zags). This will eliminate duplicate efforts and it will reduce cost.
- Revise the "Background" section of NAVSEAINST 9094.5 to avoid misinterpretation. It has been interpreted to mean test will only be conducted if funds are available when the intent is to require funding and testing as specified in NAVSEAINST 9094.5.
- Revise NAVSEAINST 9094.5 to include a requirement for assigning 56X1 technical personnel as Tri-

als Liaison Officer to coordinate trials at sea. This will assure that the trials are conducted in complete and fully satisfactory manner. The Trials Liaison Officer shall obtain CNO Project Order to conduct these trials.

- Revise Gen Spec to include NAVSEAINST 9094.5 as reference. This will improve awareness of the P&ST policy.
- Change the title from "Ship Performance Trials" to "Performance and Special Trials" in NAVSEAINST 9094.5 to be consistent with General Specifications and references [2] and [5].
- Develope a standardized NAVSEA Guidance Manual for Performance and Special Trials similar to SNAME Code C2. This manual will provide, in addition to improved awareness, proper utilization of the procedures for special mission ships which are not covered in C2.
- Include NAVSEAINST 9094.5 and P&ST Guidance Manual in the EITs training program. Have EIT candidates for SEA 90 and Engineering Directorate briefed by 56X1 on this subject to enhance awareness.
- Investigate the feasibility of establishing a NAVSEA Trials Branch.
- Conduct P&STs immediately following the AT to use the same special trial instrumentation as the BT and AT to reduce cost.
- The planning, as discussed above, should be followed judiciously by 56X1, SDMs, SHAPMs and SLMs.

REFERENCES

[1] Naval Sea Systems Command, "NAVSEAINST 9094.5 Ship Performance Trials," 1 June 1985.

[2] Naval Sea Systems Command, NAVSEA S9086-C4-STM-000, "Naval Ships' Technical Manual: Chapter 094, Trials," 1 March 1978.

[3] R.J. Stenson and L.L. Hundley, "Performance and Special Trials on U.S. Navy Surface Ships," David Taylor Research Center DTRC/SHD-1320-01, April 1989.

[4] Philip Mandel, "Ship Maneuvering and Control," Principles of Naval Architecture, J.P. Comstock, ed., SNAME, 1967.

[5] Naval Sea Systems Command, NAVSEA 0900-LP-095-3010, "Ship Post-Delivery Tests and Trials Guidance Manual," January 1982.

[6] "USS Arleigh Burke (DDG 51), Performance and Special Trials Agenda (Preliminary Report)," David Taylor Research Center, Full Scale Trials Branch, Code 1523, February 1990.

[7] O. E. Raikko and G.E. Pribbeno, "Ship Trials from Noah to Nixon," Sixth Annual Technical Symposium, ASE, 1969.

[8] "Code for Sea Trials", Technical & Research Code C2, published by SNAME, 1974.

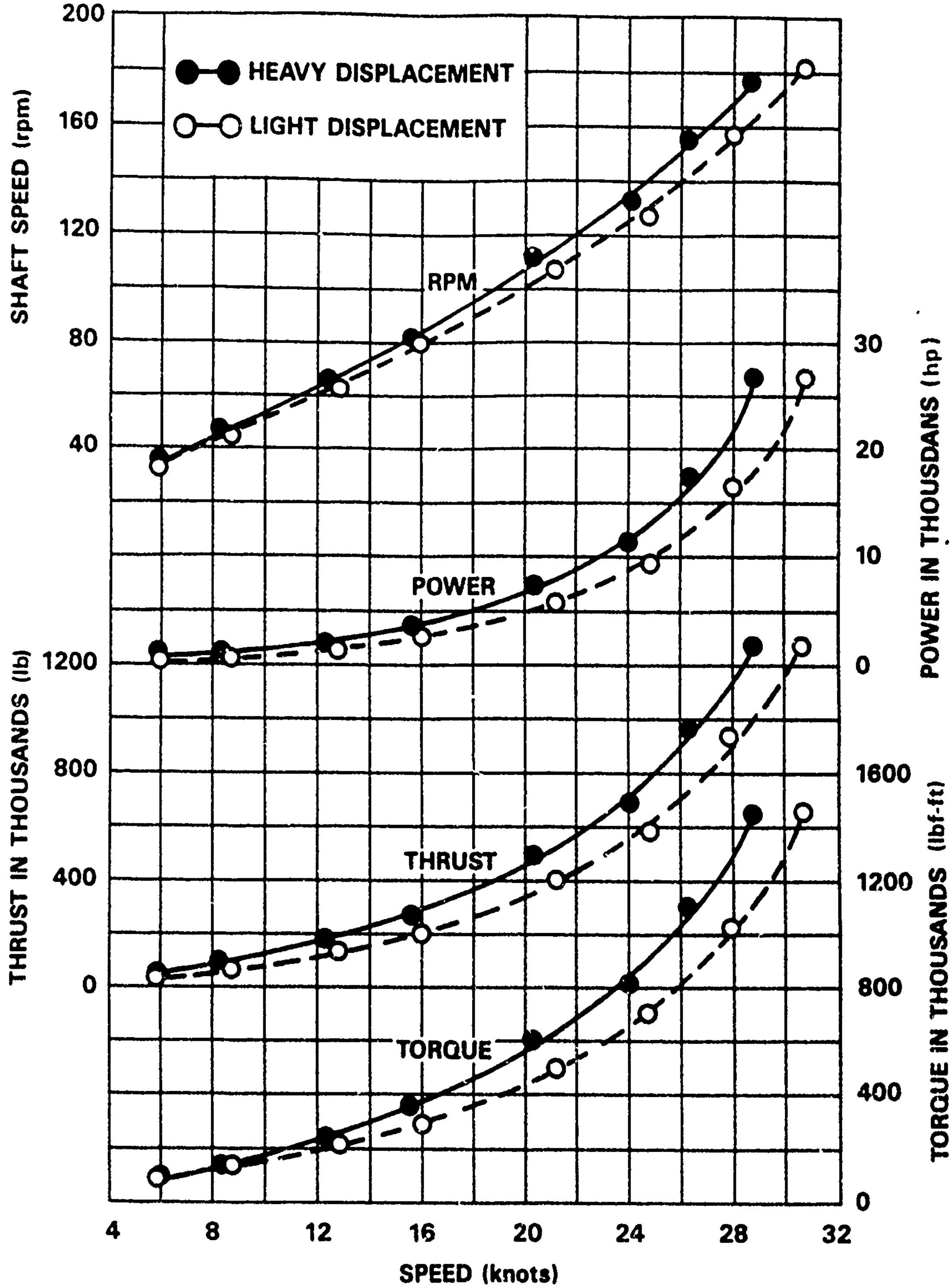

Figure 1.
Sample Standardization Trial Data

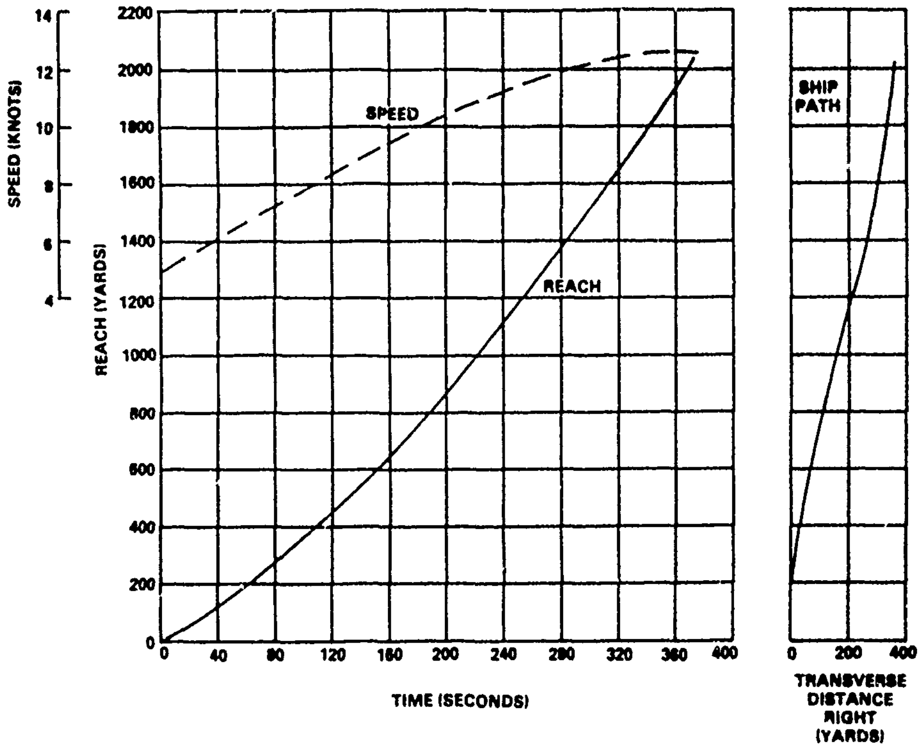

Figure 2.
Sample Acceleration Trials Data

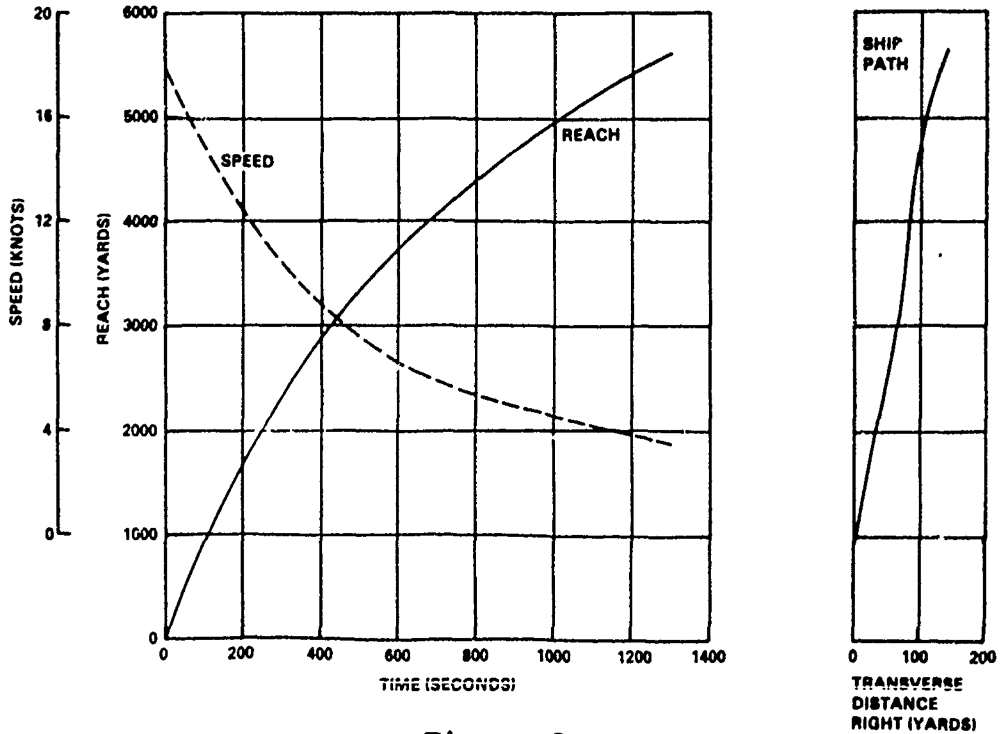

Figure 3.
Sample Deceleration Trials Data

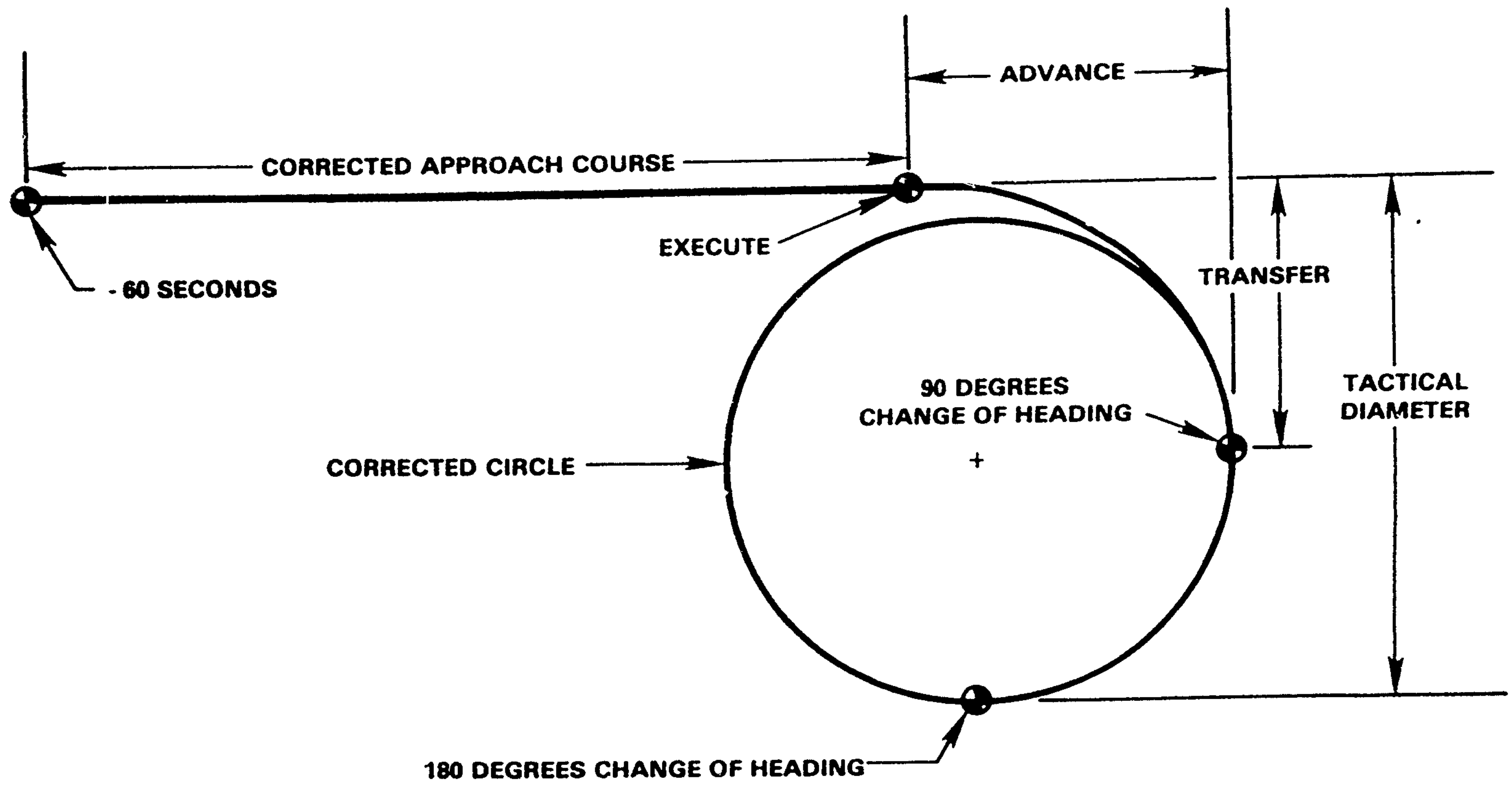

Figure 4.
Sample Tactical Circle

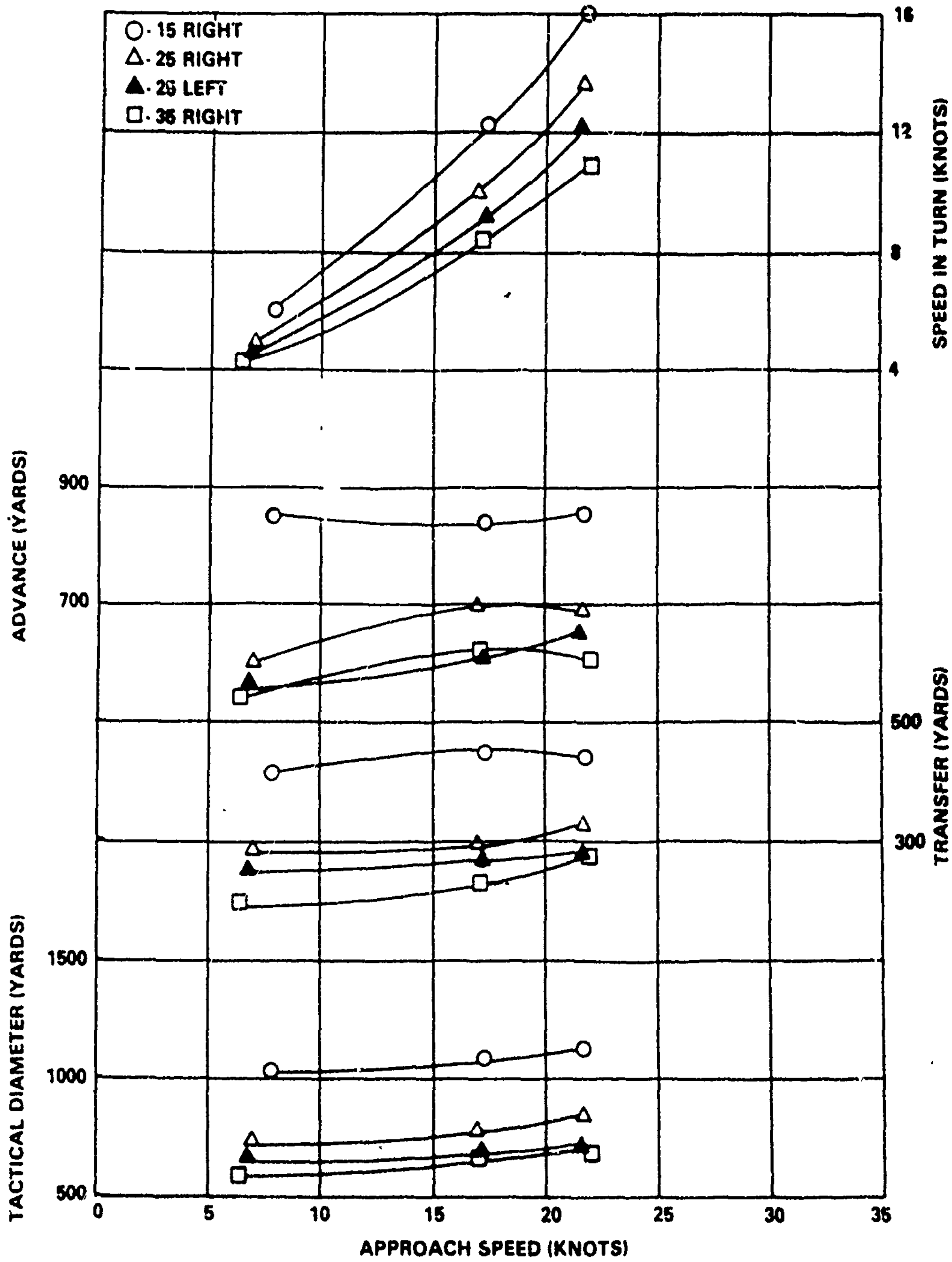

Figure 5.
Ships Turning Characteristics Plotted from Tactical Circles

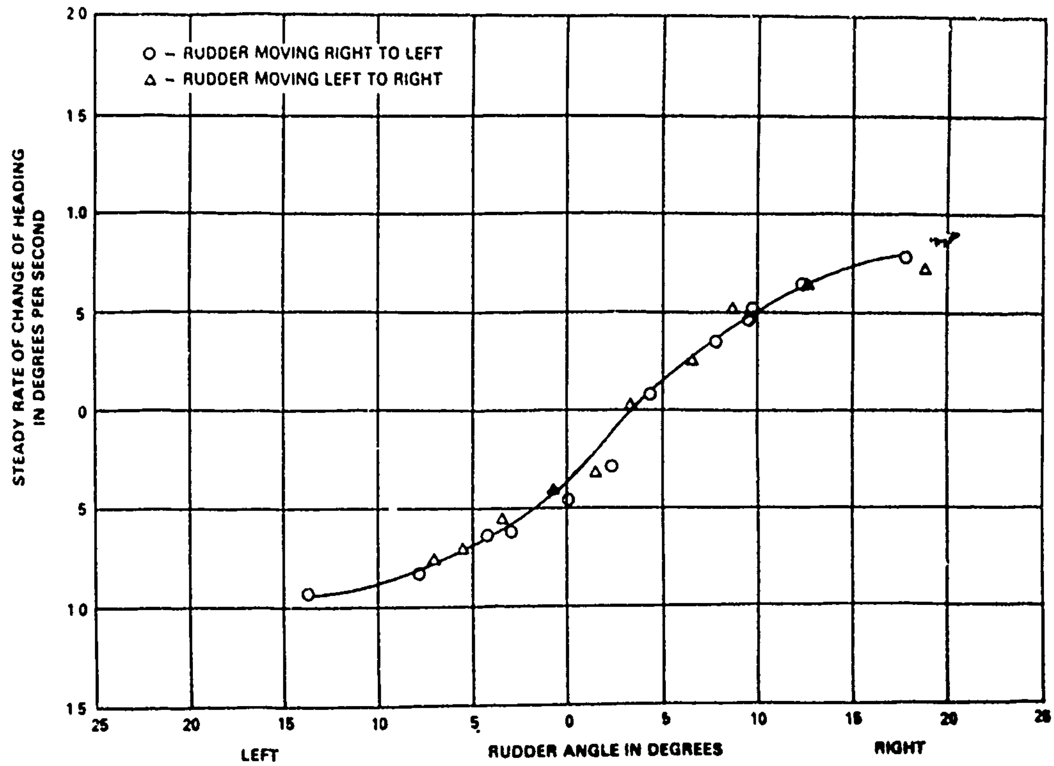

Figure 6.
Stable Ship Lateral Stability Characteristics

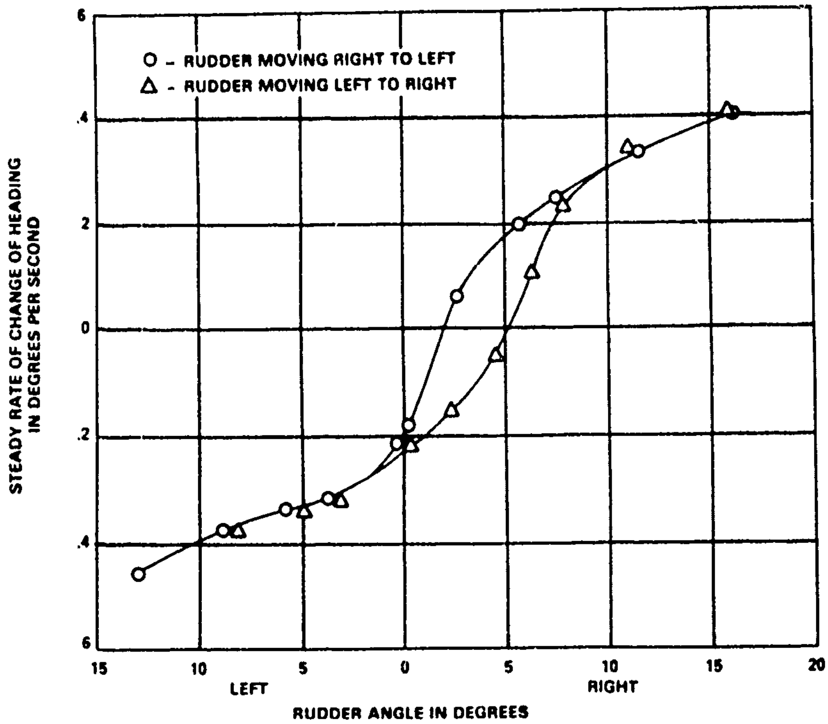

Figure 7.
Unstable Ship Lateral Stability Characteristics

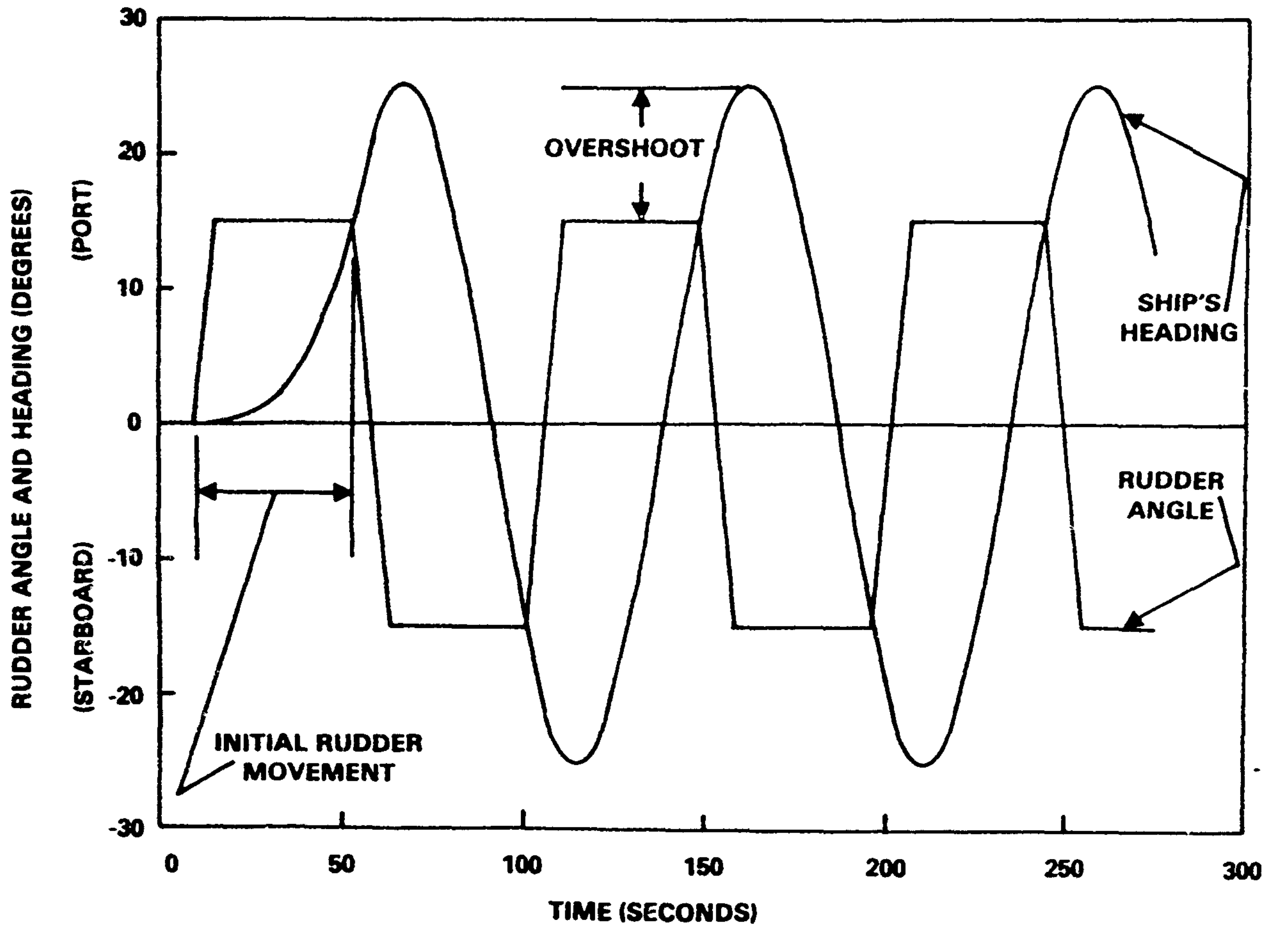

Figure 8.
Zig-Zag Maneuvers (Horizontal Overshoots) Trial Data

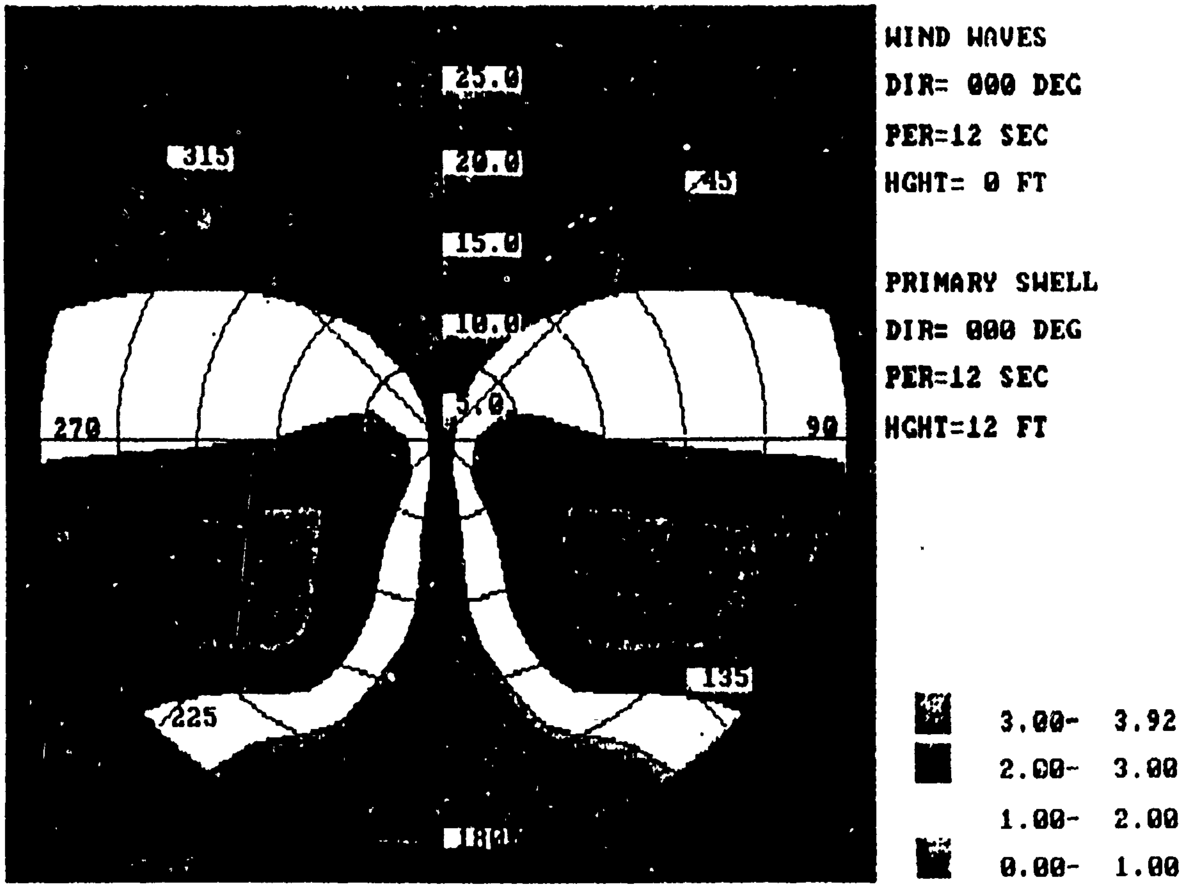

Figure 9
Sea Trial Roll Motion Example

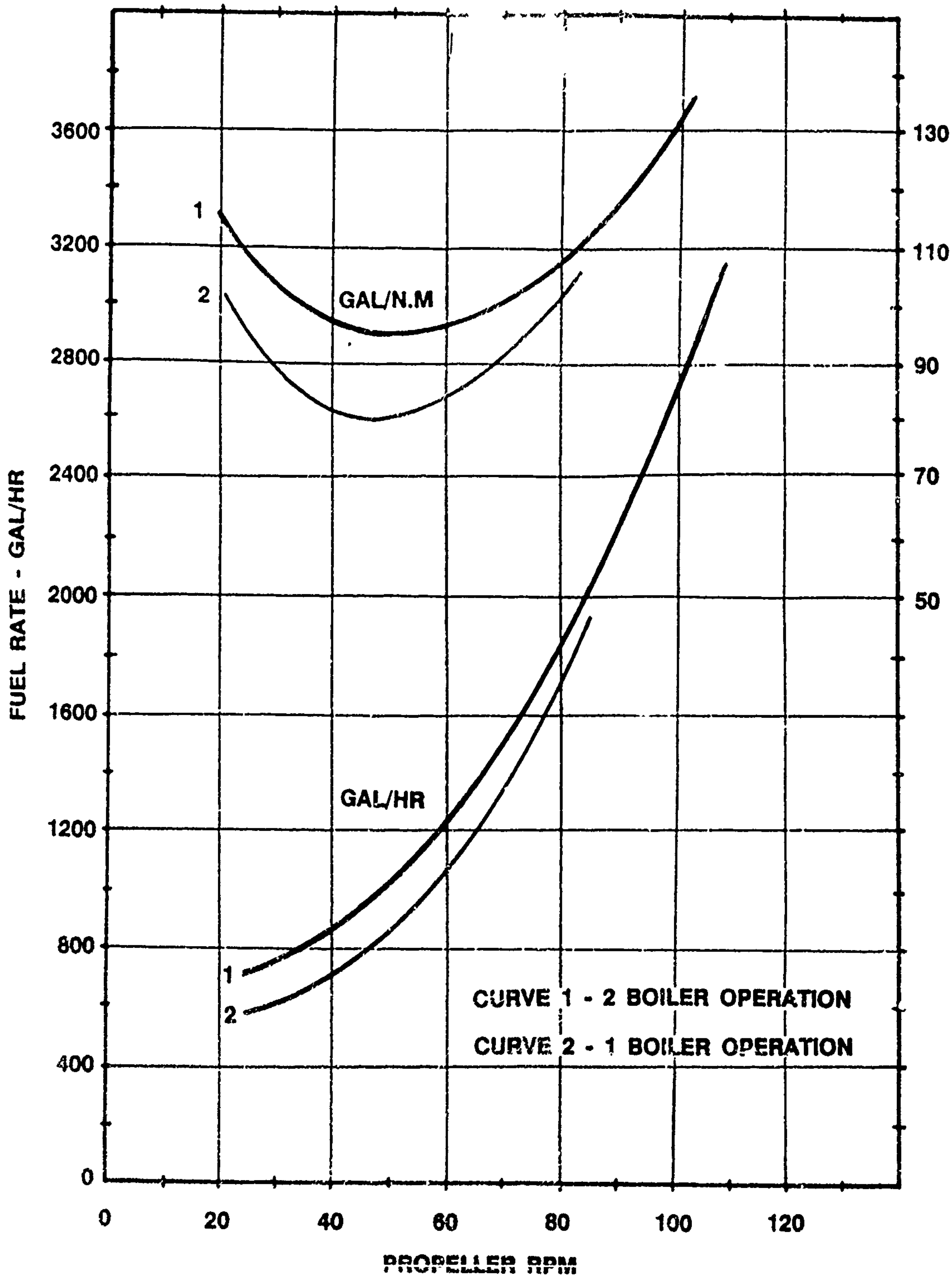

Figure 10.
Fuel Economy Trial Data

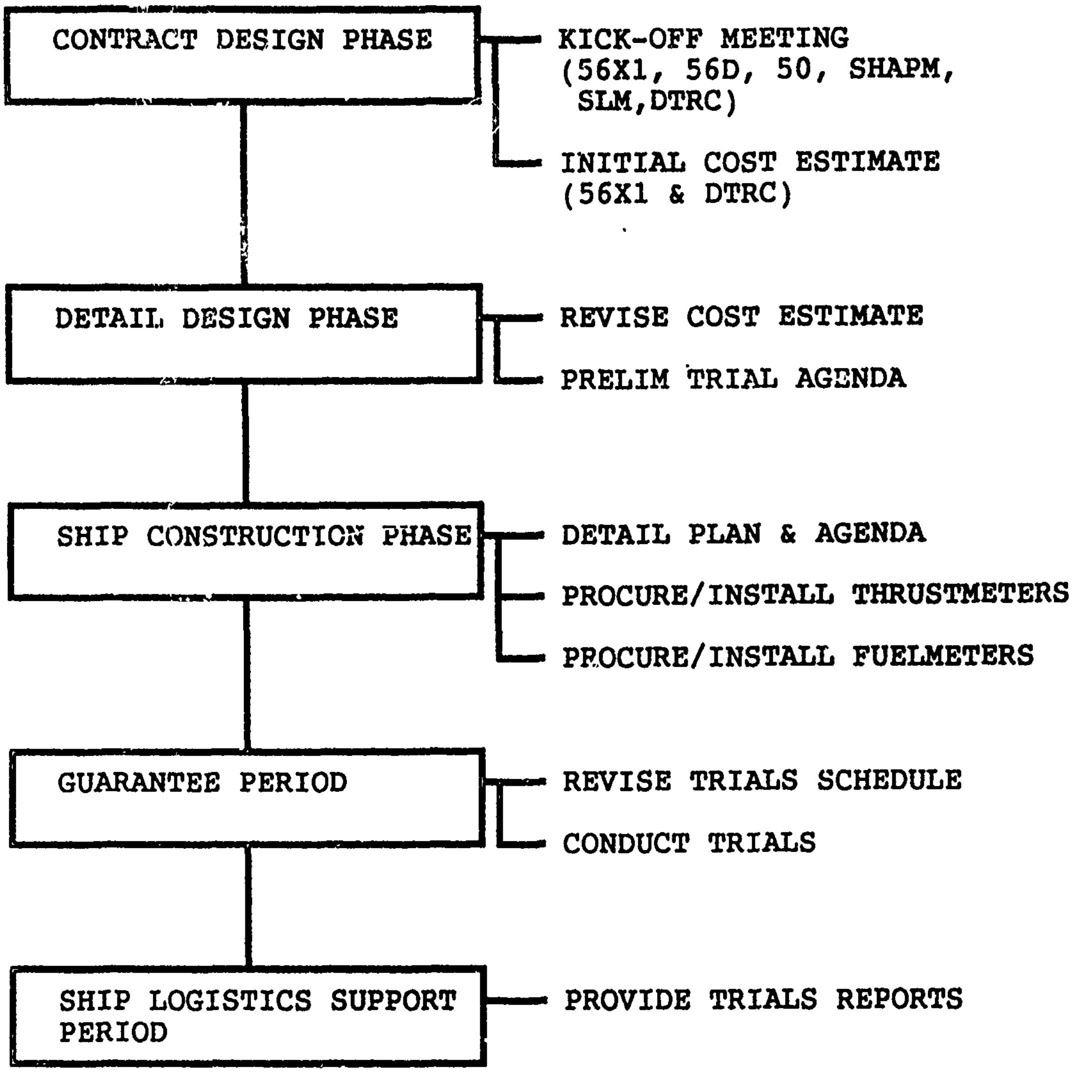

Figure 11
P&ST Flow of Main Events

AIRCRAFT CARRIER SERVICE LIFE EXTENSION PROGRAM (CV SLEP)

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The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense nor of the Department of the Navy.

Abstract

The aircraft carrier is a vital component of the force structure required by the United States to fulfill overall national defense strategy. Budget constraints and other exigencies have caused the rate of ship building in the 1970's to be less than optimal thereby prompting a search for alternatives to ensure that the required number of aircraft carriers is available to the operating forces. The Aircraft Carrier Service Life Extension Program (CV SLEP) was developed and approved to fulfill this requirement. Background information concerning the objectives, constraints, and fundamental elements of the CV SLEP program is presented. The decision process for the industrial site selection for CV SLEP is presented along with a review of the industrial effort in aircraft carriers which have completed SLEP. Finally, the evolution of SLEP to a "reduced scope" SLEP concept and the future of CV SLEP is presented.

LIST OF TABLES

ABBREVIATIONS

APM	Assistant Program Manager
AVRP	Alternative Vulnerability Reduction Program
BMT	Boiler Management Team
CEB	Chief of Naval Operations Executive Board
CINCPACFLT	Commander in Chief, U. S. Pacific Fleet
CNAL	Commander Naval Air Force, U. S. Atlantic Fleet
CNAP	Commander Naval Air Force, U. S. Pacific Fleet
CNM	Chief of Naval Material
CNO	Chief of Naval Operations
COH	Complex Overhaul
CV	Aircraft Carrier
CVN	Aircraft Carrier Nuclear
DPSB	Defense Program Strategy Board
FMP	Fleet Modernization Program
FY	Fiscal Year
GFE	Government Furnished Equipment
HVAC	Heating Ventilation Air Conditioning
INSURV	Board of Inspection and Survey
IPR	In-Process Review
NATO	North Atlantic Treaty Organization
NAVMAT	Chief of Naval Material
NAVSEA	Commander Naval Sea Systems Command
NAVSSES	Naval Ship Systems Engineering Station
O&MN	Operations and Maintenance Navy
OP-05	Assistant Chief of Naval Operations (Air Warfare)
PNSY	Philadelphia Naval Shipyard
POM	Program Objectives Memorandum
POT&I	Pre-Overhaul Test and Inspection
PRESINSURV	President Board of Inspection and Survey
PSA	Post Shakedown Availability
PSTA	Pre-Sea Trial Audit
QAP	Quality Audit Program
R&D	Research and Development
ROH	Regular Overhaul
SARP	Ship Alteration and Repair Package
SCN	Ship Construction Navy
SECNAV	Secretary of the Navy
SIAT	Ship's Installation Assurance Test
SLEP	Service Life Extension Program
SRA	Selected Restricted Availability
SUPSHIP	Supervisor of Shipbuilding, Conversion and Repair
VCNO	Vice Chief of Naval Operations

BACKGROUND

The Aircraft Carrier Service Life Extension Program (CV SLEP) had its beginning on 27 March 1975, when Admiral Holloway, Chief of Naval Operations (CNO), initiated action to study the feasibility of increasing aircraft carrier service life from 30 to 45 years as an alternative to new construction for maintaining carrier force levels into the 21st century. Eight conventional carriers were reaching their 30 year nominal service life between 1985 and 1998. Timely replacement through new construction was not feasible due to both budget and facility constraints. Approximately a year later, on 13 March 1976, Admiral Holloway conceptually approved CV SLEP and tasked the Chief of Naval Material (CNM) to provide a Plan of Action and Milestone to commence CV SLEP [1].

The objective of CV SLEP is to maintain carrier force levels by extending the life of carriers for an additional 15 years. The objective is achieved through an extensive overhaul at one quarter the cost of a new carrier. This was to be accomplished in a single shipyard availability of 28 months through a combination of ship alterations and repairs of approximately 1.6 to 1.8 million mandays of shipyard labor, dependent on the individual ship's projected material condition at SLEP commencement.

The CNO also directed that Research and Development (R&D) funding would be used for planning and Ship Construction Navy (SCN) funding would be used for the industrial effort, outfitting and post delivery support. The CNO Execute Board (CEB) further stipulated a 28 month availability that the Fleet Modernization Program (FMP) alterations be equivalent to those which the ship would receive during a complex overhaul (COH), and a ship's force complement of approximately 1500 personnel [2]. The 28 month availability was selected as the duration best meeting overall program objectives while causing the least disruption to carrier operating schedules.

The initial program constraints imposed were:

- SLEP is a substitute but not a replacement for a new carrier.
- Dollars/time limit the amount of work that can be accomplished during the SLEP industrial period.
- Low priority work may have to be deferred to a subsequent COH or selected restricted availability (SRA).
- SLEP is not intended to upgrade the ship to current specifications. Basic ship design/dollar/time constraints will preclude fully achieving the latest standards in such areas as habitability and heat stress.
- Following SLEP, each carrier would follow its regular overhaul and restricted availability schedule.

The industrial effort of CV SLEP had these three fundamental elements [3]:

- Fleet Modernization Program (FMP) consisting of those military improvements which a carrier would receive during a normal COH.
- Life Enhancing Alterations consisting of selected ship systems capability upgrades to improve operations, reliability, and maintainability.
- Ship system repairs providing extensive repairs/replacement of machinery, equipment and structures.

These fundamental elements of the CV SLEP industrial period provide the basis of comparison between SLEP and an overhaul. The following are characteristics of the SLEP industrial period:

- Increase in the scope of repairs to basic hull, power generation systems, and auxiliary systems.
- Upgrading of basic support systems capabilities to meet present and future weapons system requirements.
- Reduce the stress on the propulsion system equipments and personnel by upgrading the aircraft launch and recovery systems.
- Replacement of equipments no longer supportable or requiring excessive maintenance.
- Accomplishment of life-enhancing alterations.

PROGRAM MANAGEMENT

The Assistant Program Manager (APM) for CV SLEP (PMS312C) has clear responsibility for authorizing the work package during the Work Definition Conference. Work authorization, both modernization and repair, is based on:

- Fleet Modernization Program.
- Identified deferred work from the current ship's maintenance project or discrepancies from the Board of Inspection and Survey (INSURV).

- Prediction of equipment requiring replacement based upon supportability, service life expiration, and obsolescence.

- Pre-Overhaul Test and Inspection (POT&I) recommendations.

- Alteration shipcheck.

- Governing program priorities.

There are many activities, both technical and operational, involved in making recommendations for work and its priority for accomplishment, but the APM for CV SLEP is clearly responsible for authorizing that work that ultimately will be accomplished. If there is disagreement with his decisions, the other activities have recourse to higher authority (ultimately the program sponsor, Assistant Chief of Naval Operations (Air Warfare) (CNO OP-05)) for clarification of priorities. Therefore, the APM authorizes the specific work, and as is the standard practice, the work is to be performed by the execution shipyard in accordance with accepted Navy technical procedure. The initial work authorization is documented in the Ship Alteration and Repair Package (SARP). For SLEP, subsequent recommendations for new work or growth in scope within previously authorized work items, are also the responsibility of the APM for either authorization or deferral. These decisions are made based on the works items technical and/or operational necessity and program impact. Both aspects must be considered as the APM is responsible for both cost and schedule as well as performance. Often program implications must override technical considerations unless safety and/or the ship's ultimate ability to meet mission requirements are an issue. Again there is always recourse to higher authority in the case of disagreement or the fact that technical or operational concurrence cannot be obtained in making the decision(s) to defer work.

SITE SELECTION

The selection process of the shipyard, either private or public, for the initial and possibly all subsequent CV SLEP ships has had a very interesting and dynamic history. On 23 July 1976, in a letter to the Chief of Naval Operations, the Commander Naval Sea Systems Command (NAVSEA) recommended that Philadelphia Naval Shipyard (PNSY) be the initial CV SLEP overhaul activity for the reasons given below:

- PNSY retained new ship construction capability and large carrier drydock which will minimize the acquisition of facilities needed to start the program.

- Regular overhauls in homeport of other ships would not be displaced as would be the case if SLEP were performed at Puget Sound or Norfolk Naval Shipyards.

- CV SLEP availabilities at Philadelphia should permit return of a number of currently scheduled out-of-homeport regular overhauls (ROH) back to Charleston and Norfolk Naval Shipyards.

- Minimum disruption of existing fleet overhaul work would be experienced by not adding CV SLEP to Puget Sound or Norfolk Naval Shipyard.

NAVSEA also recommended in this letter that the CV SLEP availability be 28 months in duration and that the ship alteration level of effort be held to no more than 150,000 mandays.

Subsequent to this letter, no decision was made by the CNO concerning the assignment of the execution yard for CV SLEP pending a decision on the civilian ceiling point adjustment by the Department of Defense. The CNO at this time noted that the key point was that while the Navy was looking to raise the civilian ceiling for Philadelphia by 3500, the trend within the Department of Defense was to make an overall 2% civilian cut within the Navy. Concurrently, due to possible civilian constraints in the public shipyards, the Navy began investigating the pros and cons of Philadelphia Naval Shipyard and Newport News Shipbuilding and Drydock Company as the SLEP execution yard. In a letter to the CNO, and endorsed by the Chief of Naval Material, NAVSEA on 10 November 1977 recommended that Newport News Shipbuilding and Drydock Company be designated as the first SLEP execution yard. NAVSEA's change from Philadelphia Naval Shipyard to Newport News Shipbuilding and Drydock Company was based on the:

- Apparent belief that naval shipyards will have constrained ceilings.

- Newport News Shipbuilding and Drydock Company work force could readily accept the ship without requiring early build up and training and associated start up costs.

However, on 24 April 1978, in a message to the Chief of Naval Material, the CNO assigned Philadelphia as the execution yard for CV SLEP for four Forrestal (CV 59) class aircraft carriers [4]. This action was followed by the Byrd/Trible Amendment to the Defense Authorization Bill of 1978 which imposed the following restrictions on CV SLEP:

No action may be taken with respect to public or private shipyard assignment of CV SLEP until:

- A new least cost study of the comparative costs (public vs. private) is submitted following enactment of the Authorization Bill.
- A period of 60 days of a continuous session of Congress expires following submission of the cost comparison.

A cost comparison conducted during the summer to fall 1978 period, showed a difference in economic cost of SLEP in favor of Newport News over Philadelphia due primarily to the amount of crew retained to accomplish the industrial effort [5]. The options facing the Navy at this time due to the amendment and the agreed upon required minimum of 24 months of advanced planning necessary to start SLEP were:

- Delay the entire program until Congressional approval/disapproval of the Secretary of the Navy's decision. This was an impact of six months.
- Overhaul USS SARATOGA starting in October 1980 and commence SLEP with the second ship in January 1983 as scheduled.
- Overhaul USS SARATOGA starting in October 1980 and move the USS FORRESTAL SLEP date forward to the earliest feasible start date ensuring 24 months provided for industrial planning.
- Commence SLEP on time with USS SARATOGA, accepting only 18 months of planning vice 24 months.
- Reverse the decision, send SLEP to Newport News to commence on time.

Due to the uncertainties, caused by Congressional interest in the assignment of the first CV SLEP ship, Secretary Pyatt (Assistant Secretary of the Navy (Shipbuilding and Logistics)) in a memorandum dated 8 September 1978 to the CNO, directed dual planning be initiated at both Newport News and Philadelphia to ensure both shipyards would be in a position to execute CV SLEP upon final assignment. Dual planning for CV SLEP was also provided for in Section 811 of the Department of Defense Appropriation Authorization Ac. of 1979, Public Law No. 95-485, 92 Stat. 1611, 1624 (October 20, 1978) which expired on close of business 24 May 1979. On 25 January 1979, in accordance with the Byrd/Trible Amendment to the Defense Authorization Bill of 1978, a least cost study of CV SLEP was submitted to Congress and the Navy under took preparations to assign final work to the Philadelphia Naval Shipyard as early as April 1979. Upon compliance with Section 811 of the Defense Authorization Bill at the close of business on 24 May 1979, the Navy proceeded with the execution of the Deputy Secretary of Defense's decision in January 1979 to assign CV SLEP to Philadelphia. On 25 May 1979, the Secretary of the Navy in a memorandum ceased dual planning for CV SLEP. Final approval of Philadelphia Naval Shipyard as the first CV SLEP shipyard was provided by a conference report on Department of Defense Supplement Appropriation Authorization Act, 1979 which left determination of shipyard assignment to the Secretary of Defense, taking into account considerations of cost, National Security, and such other factors as he considers appropriate. This conference report was approved by both Houses of Congress on 18 June 1979. Subsequently, USS SARATOGA (CV 60) SLEP commenced at Philadelphia Naval Shipyard on 1 October 1980.

Based upon the CNO's decision of 24 April 1978 to assign Philadelphia Naval Shipyard as the execution yard for CV SLEP for four Forrestal (CV 59) class aircraft carriers, the conference report of 18 June 1979 approved by both Houses of Congress that assigned Philadelphia Naval Shipyard as the first CV SLEP shipyard, and because USS FORRESTAL CV SLEP detailed advance planning was well underway, there was no apparent disagreement among the public and private sector about the assignment of USS FORRESTAL (CV 59) to Philadelphia Naval Shipyard for CV SLEP. The Secretary of the Navy made this announcement on 5 September 1980. However, during the later half of the SLEP availability of USS SARATOGA, cost analysis of assigning USS INDEPENDENCE (CV 62) to PNSY or Newport News Shipbuilding and Drydock Company was again being performed. This analysis developed the total economic costs to the government of performing an identical ship modernization work package in either shipyard and addressed such issues as shipyard workload capacity, material, labor, and overhead costs, profit, taxes, depreciation, cost of capital, participation of the ship's crew, and other lesser considerations that impact costs. Even with all these variables involved, the cost differences for doing SLEP at PNSY or Newport News Shipbuilding and Drydock Company were so close as to be withinthe accuracy of the estimates themselves. Therefore, with no clear cut cost advantage that came forward from the analysis, NAVSEA recommended that SLEP continue at the Philadelphia Naval Shipyard and forwarded this recommendation to OP-05 on 15 June 1982 [6]. OP-05 forwarded this same recommendation to the CNO on 15 July 1982 [7].

Driving the program office at NAVSEA at this time was the knowledge that experience to date in planning both the SARATOGA and FORRESTAL SLEPs showed

that work planning and procurement of long lead time material should commence 30 months vice the previously stated minimum of 24 months, prior to availability start date. Accordingly, for optimum planning and lead time, it was desirable by all, that USS INDEPENDENCE SLEP site be announced no later than October 1982. Slippage beyond that time could lead to increased costs and the potential for delay and disruption to the overhaul itself. Admiral Watkins, CNO, recommended that USS INDEPENDENCE SLEP be assigned to PNSY on 15 July 1982 [8].

The site selection argument for CV SLEP ships after USS INDEPENDENCE SLEP took upon a different flavor, primarily because the next three ships scheduled for SLEP, (USS KITTY HAWK (CV 63), USS RANGER (CV 61) and USS CONSTELLATION (CV 64)) were all stationed on the West Coast. In this respect, the argument as to where SLEP should be executed did not originate from a public versus private shipyard basis, but from a geographical and duration basis.

In preparation for West Coast aircraft carriers to undergo SLEP, Commander Naval Air Force U. S. Pacific Fleet (CNAP) made it quite clear that he preferred to conduct a shorter availability on the West Coast for USS KITTY HAWK (CV 63), the first West Coast aircraft carrier scheduled for SLEP. CNAP proposed conducting a "reduced scope" SLEP of 18 months at Puget Sound Naval Shipyard. The position of CNAP was predicated on the following factors:

- Availability of Pacific based aircraft carriers to meet operational commitments.
- Loss of carrier unique industrial capacity on the West Coast if SLEPs are performed at Philadelphia.
- Impact on crews and dependents resulting from coast to coast transfers at the start and completion of SLEP.
- Many of the ship alterations included in the first three SLEP ships were already installed in CV 63.
- CNAP aircraft carriers have longer SRAs, overhauls and more frequent upkeep periods than Commander Naval Air Force U. S. Atlantic Fleet (CNAL) ships; therefore, many SLEP type repairs have already been accomplished in CNAP ships.

NAVSEA, in response to CNAP's proposal, completed a site selection study for industrial assignment of USS KITTY HAWK SLEP in May 1984. The results of the study indicated that costs were shown to favor an assignment to Philadelphia Naval Shipyard, however, costs did not provide a clear enough differential for assignment on that factor alone. Projections of manday rates at Philadelphia and Puget Sound verified that to be the case. Workload considerations was the major reason for the recommendation for assignment to Philadelphia. While NAVSEA concluded that it was technically feasible to conduct SLEP at Puget Sound, the SLEP availability at Puget Sound would require a major increase in the Puget Sound end strength or reassigning availabilities and delaying other ship starts. Other factors such as facility support and program continuity were also considered.

The decision of site selection for CV 63 SLEP was required no later than December 1984, however, NAVSEA desired an earlier decision to ease the problems associated with CV 63 being the first of three west coast carriers to be included into the program and to mitigate the problems caused by the ship's reduced accessibility for ship checks due to its location [9].

Ultimately, the site selection of USS KITTY HAWK SLEP was decided by Secretary Pyatt on 1 February 1985. On that date, Secretary Pyatt, the Assistant Secretary of the Navy (Shipbuilding and Logistics), stated in a memo to the Vice Chief of Naval Operations (VCNO), "In light of current plans to perform all future SLEPs at Philadelphia Naval Shipyard, it is no longer considered necessary to perform site selection studies. You may stop performing site selection studies as of this date [10]." This indeed was a significant milestone in the history of CV SLEP because, for the first time, the advanced planning phase of each future SLEP ship would not be handcuffed awaiting the decision as to where the ship would be overhauled during SLEP.

However, even after Secretary Pyatt's statement in February 1985, assigning Philadelphia Naval Shipyard as the SLEP execution shipyard, Congressional interest in the assignment of USS KITTY HAWK SLEP was still a concern. NAVSEA was continually justifying the selection of Philadelphia Naval Shipyard as the SLEP shipyard for CV 63. The House Armed Services Committee FY86 Report #99-81 concurred that extension of the service life of aircraft carriers is a cost effective method of maintaining Naval forces. However, it requested amplifying information regarding the cost effectiveness of performing the effort in a single long shipyard period in Philadelphia versus accomplishing the effort during a complex overhaul (COH) and a series of short maintenance periods that could be accomplished by West Coast yards. In a letter to the CNO in September 1985, NAVSEA again reiterated that cost studies show an advantage for completing SLEP at Philadelphia versus the incremental approach proposed

for West Coast facilities. Besides the lower manday rates projected for CV 63 SLEP at Philadelphia versus Puget or San Diego or San Francisco, NAVSEA argued that the incremental maintenance concept would also result in a 10 percent increase in overall cost to accommodate the disruption and inefficiencies associated with periodic start up costs for each incremental maintenance period.

On 25 November 1985, in a letter to Representative Les Aspin, Chairman, Committee on Armed Services, John Lehman, Secretary of the Navy wrote, "I have concluded that completing SLEP in a single availability at Philadelphia Naval Shipyard is the most cost effective means of achieving the goals of the aircraft carrier service life extension program [11]."

Similarly in response to the Senate version of the FY86 Defense Authorization Bill, Sec 2 of Senate Bill S.1029, John Lehman, Secretary of the Navy notified Senator Barry Goldwater, Chairman of the Senate Armed Services Committee that "I hereby certify, all relevant factors considered, a full SLEP at Philadelphia Naval Shipyard is more cost effective than alternative means for achieving the same service life extension of USS KITTY HAWK at other naval shipyards [12]."

These two letters, have for the moment, put to rest the nine year debate, discussion, and analysis to determine which shipyard is best qualified to support the industrial requirements of CV SLEP. Philadelphia Naval Shipyard has been assigned as the industrial shipyard to overhaul all future aircraft carriers scheduled for SLEP.

"REDUCED SCOPE" SLEP

The argument for a "reduced scope" SLEP was first made by Commander Naval Air Force, U. S. Pacific Fleet (CNAP) during the advance planning phase for USS KITTY HAWK (CV 63) SLEP, the first of three CNAP carriers scheduled for SLEP. CNAP proposed conducting a "reduced scope" SLEP of 18 months. After careful review of CNAP's proposal, both NAVSEA and NAVMAT recommended a full scope SLEP for CV 63 to comply with meeting the objectives of SLEP as defined by the CNO. In August 1984, NAVSEA recommended that the duration of CV SLEP for both USS KITTY HAWK (CV 63) and USS CONSTELLATION (CV 64) be a minimum of 24 months. This assessment was based upon SLEP experience to date, plus computation of heel-to-toe work sequencing, through the main spaces and on the flight deck where final catapult testing is dependent upon main space light off and the availability of steam. A duration of 24 months was concluded by NAVSEA to provide the 30 days minimum allowed for growth and only six months to conduct production testing and trials. NAVSEA emphasized that deletion of either of these allowances placed both CV 63 and CV 64 SLEP availabilities at extreme risk [13].

The argument for a "reduced scope" SLEP however, was not resolved at this level of the Navy chain of command. Responding to concerns expressed by Commander in Chief, U. S. Pacific Fleet (CINCPACFLT) regarding Pacific Fleet carrier scheduling and west coast industrial continuity, the Vice Chief of Naval Operations (VCNO) requested the feasibility of conducting a "reduced scope" SLEP be investigated. Shortly thereafter, the SLEP budget proposed in Program Objectives Memorandum (POM) 86 was reduced at the May 1984 Department of the Navy Strategy Board to provide for 18 month funding which just happened to coincide with the availability length proposed by CNAP. Since CV SLEP had previously been programmed for a 28 month duration, the across-the-board budget reduction set the budget at 18/28ths, 64% of the previous level, to 1.1 million mandays, which is 64% of the previous production manday level of 1.7 million mandays.

Based upon the arguments presented by CNAP, several "reduced scope" SLEP options and a number of alternatives surfaced as being feasible, given that the basic availability was at least 24 months in duration to accommodate the critical path work in the propulsion spaces and the flight deck as previously described. The Assistant Secretary of the Navy (Financial Management) in a 16 October 1984 memorandum, reaffirmed the Secretary of the Navy's intent to reduce the cost of SLEP and retain the 28 month industrial duration. Further, he stipulated that SLEP should continue to be planned for Philadelphia Naval Shipyard. This decision meant that SLEP for USS KITTY HAWK and USS CONSTELLATION was capped at 1.1 million mandays, each for a duration of 28 months.

With this constraint of 1.1 million mandays, NAVSEA reduced the size of the FMP package to concentrate on those alterations essential to keep pace with war fighting improvements and still be able to meet the objectives of CV SLEP as defined by the CNO. Even though CNAP was working on SLEP-type repairs in tank and piping systems in USS KITTY HAWK prior to USS KITTY HAWK SLEP, the funding cap still forced NAVSEA to defer numerous repairs from USS KITTY HAWK SLEP that had previously been accomplished on the first three SLEP ships. What resulted from this review by NAVSEA was an alteration package that included key improvements needed to update the ship's combat systems, achieve mandatory improvement in the propulsion area, and complete the necessary flight deck upgrades. It became apparent to NAVSEA that the effect of less installation mandays allocated for USS KITTY HAWK SLEP, combined with government furnished equipment (GFE)

requirements that were twice that of USS FORRESTAL SLEP, reduced the dollars available for life extending repairs. At the same time, NAVSEA was also concerned that the alteration package should include such items as survivability, fire fighting, fire protection and safety upgrades.

With this concern in mind, NAVSEA in the January 1985 presentation to the CNO Executive Board (CEB), recommended additional alterations and repairs be included in USS KITTY HAWK SLEP to increase the ship's post SLEP reliability, thereby minimizing the ship's force post SLEP maintenance burden. These recommendations totaled about $89 million, which was approximately 12 percent greater than the budget for USS KITTY HAWK SLEP at that time. To obtain such funding, two alternatives were presented by NAVSEA to the CEB. First, maintain SCN level, and commit Operations and Maintenance Navy (O&MN) funds for the out years to complete critical repairs and selected life enhancing alterations incrementally in the out years. Second, increase SCN funding levels slightly in FY87 and out, thereby completing all life extension work in SLEP and reduce the O&MN budgets. NAVSEA's recommendation was to increase the SCN funding level in FY87 and out, thereby realizing nearly all of the advantages of the first three SLEP ships, reducing the ship's force post SLEP maintenance burden, better balance the work package with the duration of SLEP, have minimum impact on the existing shipyard manning and workload, and reduce the cost of SLEP by 20 percent from the original POM 86 submission.

Based on NAVSEA's recommendation, the January 1985 CEB concluded that both USS KITTY HAWK and USS CONSTELLATION would be reaffirmed as full scope SLEPs with funding capped at 80 percent of previous SLEPs or 1.44 million mandays. The reasons for this decision were, both ships were in better material condition entering SLEP, the CNO objectives for SLEP would be met in a single availability, and to take advantage of the increased shipyard productivity efficiencies. Similar to the debate about CV SLEP industrial site assignment, the concept of a "reduced scope" SLEP also had Congressional interest. As mentioned previously, the House Armed Services Committee FY86 Report #99-81 requested amplifying information regarding the cost effectiveness of a single, long shipyard period. In response, NAVSEA in a letter to the CNO in September 1985, noted that the initial off-line period for "reduced scope" SLEP would be approximately 18 months versus 30 months for a full scope SLEP. However, with the incremental approach advocated by CNAP, the subsequent short availabilities would be extended 1 to 2 months over a 7 to 10 year period to accomplish work normally completed in SLEP. With either approach, NAVSEA indicated that the Navy would maintain desired force levels including required carrier battle groups at all times. However, because SLEP restores reliability and maintainability in a single industrial period versus CNAP's proposal to approach the same objectives incrementally, SLEP ensures a higher and more sustained operational availability for carriers during the extended life phase. Therefore, NAVSEA concluded that SLEP enhances the overall fleet readiness posture and reduces the maintenance burden for fleet personnel and the Type Commander more efficiently than the incremental approach advocated by CNAP.

Based upon these arguments, NAVSEA concluded that completing SLEP in a single availability at Philadelphia Naval Shipyard would be more cost effective than completing SLEP incrementally on the west coast due to lower manday costs at Philadelphia, the elimination of incremental start up costs, and an overall higher state of sustained readiness for the subject carrier [14].

POM 87 BUDGET GUIDANCE

In May 1985, by direction of Defense Program Strategy Board (DPSB) POM 87 guidance, SLEP duration and start date revisions were required for INDEPENDENCE and KITTY HAWK SLEPs. The first impact, was that the CV SLEP budget line was slipped one year to the right. The second impact, was that the INDEPENDENCE work package should be restructured for accomplishment in the most cost efficient manner based on single shift schedule with no weekend nor overtime work. The third impact, was that INDEPENDENCE SLEP duration be extended 6 to 12 months. The fourth impact, was that KITTY HAWK SLEP work package be reviewed for accomplishment in the most cost efficient manner.

Responding to DPSB POM 87 guidance, PNSY concluded that full SLEP work packages as executed on SARATOGA and FORRESTAL can be accomplished most efficiently with a 34 month availability, a 70/30 split between day and night shifts, plus about 4 percent overtime. The first two SLEPs were of 28 month duration, conducted with a 60/40 split and up to 19 percent overtime. It is important to note that PNSY's recommendation was based upon the argument that the marginal cost for the recommended back shift and small overtime percentage is small compared to the production efficiencies gained in set-up time, work and skill trade sequencing and the avoidance of interruptions in testing, services, and tool and material availability. Since the cost of shift work is less than the cost for overtime, it is more cost effective to limit overtime and plan to meet the work requirements outside the first shift through the use of back shift workers, provided manning and trade skill balances allow you to do so.

NAVSEA's recommendation, based upon PNSY input, was to accompish INDEPENDENCE in 34 months vice 37 months, start KITTY HAWK in FY88 in accordance with DPSB POM 87 guidance and start CONSTELLATION SLEP in FY90 vice FY91. The recommended length of USS KITTY HAWK and USS CONSTELLATION SLEPs would be 30 months. The argument presented by NAVSEA was that this schedule was the most cost efficient considering the shipyard loading, manpower availability, scheduling and work packages of each ship.

OP-05 also recommended the above schedule vice 37 months for all three ships. This schedule was also endorsed by both fleet Type Commanders.

The results of the August 1985 CEB concurred with NAVSEA's proposal that the SLEP schedule would be 34-30-30 months for USS KITTY HAWK, USS CONSTELLATION and USS RANGER. Magazine side protection backfit was to be included into USS CONSTELLATION SLEP. In November 1985, OP-05 requested a feasibility study be conducted to determine if USS KITTY HAWK magazine side protection (MSP) backfit could be scheduled into her FY88 SLEP. In December 1985, NAVSEA responded to OP-05 indicating that MSP may be feasible for CV 63 with drydock size limitation a key consideration. In a letter dated 25 December 1985, OP-05 directed NAVSEA to continue feasibility studies for installation of MSP in CV 63 during her FY88 SLEP. This was later confirmed in a 14 June 1986 message from OP-05 to NAVSEA which stated that SCN funding for MSP and Hull Expansion (HE) during USS KITTY HAWK SLEP is part of POM 88 budget submission, and therefore NAVSEA should continue planning, engineering and design for installation of these proposed ship alterations. On 12 January 1987, OP-05 directed NAVSEA to redesign the MSP ship alteration for installation without HE, with no weight compensation required, and provide a SLEP schedule impact of the new design. This direction was further amplified on 10 September 1987 in a memo from the VCNO to OP-05 which stated that CNO has reaffirmed the decision that the MSP alteration be deleted from the CV 63 SLEP package. Later in the month, $100 million was provided to improve the survivability of CV 63, which in essence capped the cost expenditures for any new survivability ship alterations for CV 63. In response to OP-05 direction of January 1987, NAVSEA concluded in a letter to OP-05, that due to the emergent program impacts identified as the detailed design of MSP has progressed, coupled by the growing naval architectural characteristic degradation, that the MSP alteration for USS KITTY HAWK FY88 SLEP be rescinded [15]. Based upon this recommedation, OP-05 canceled MSP and recommended reduced magazine vulnerability alterations for CV 63 SLEP in February 1988 [16]. These actions eventually drove USS KITTY HAWK SLEP duration to 37 months at a funding level of 1.7 million mandays.

CV SLEP EXECUTION

USS SARATOGA (CV60), the first aircraft carier assigned to CV SLEP, entered Philadelphia Naval Shipyard on 1 October 1980 to commence a scheduled 28 month availability. The authorized work package emphasized repairs required to ensure extended life and reliable steaming. Repairs included in-depth restoration of basic hull, power generation and auxiliary systems to ensure support of present and future weapons system requirements. Modernization included installation of state-of-the-art air search radars, Close-In Weapons System, North Atlantic Treaty Organization (NATO) Sea-Sparrow Missile System, fire-fighting improvements including the HALON fire suppression system for the main machinery spaces and improved handling systems for air-launched weapons. Having had over 1.6 million mandays of industrial work accomplished, USS SARATOGA departed PNSY as scheduled, 1 February 1983 and within cost.

During the ensuring shakedown period, SARATOGA completed all post-SLEP shakedown events and system certifications as scheduled including two underway trials where full power operations were demonstrated. On completion of INSURV Final Contract Trial the week of 19 June 1983, the decision was made to replace all boiler superheater tubes to ensure long-term boiler reliability, judged inadequate due to recurrent leakage problems. The boiler superheater tubes in CV 60 were welded using a process called ASTRO-ARC. This process was expected to eliminate problems previously experienced in superheater weld integrity. However, PNSY experienced problems during installation of the new tubes in CV 60 due to equipment design, poor quality preparation of headers and tubes for welding while in the industrial environment, and poor welder proficiency/training in the ASTRO-ARC technique [17]. The boiler rework was executed concurrently with a scheduled Post Shakedown Availability (PSA) in Mayport, Florida. USS SARATOGA PSA was scheduled from 25 June 1983 to 15 September 1983. The boiler restricted availability commenced on 25 June 1983 and was extended to 3 November 1983. The repairs conducted on CV 60 boilers used a specifically organized repair team composed of mechanics from PNSY and private contractors working for Supervisor of Shipbuilding Conversion, and Repair (SUPSHIP) Jacksonville. The boiler rework in CV 60 totaled approximately $18.3 million. After completion of all boiler repairs and PSA, SARATOGA completed all pre-deployment training as scheduled including a most successful Operational Propulsion Plant Examination. SARATOGA's perfor-

mance in these post SLEP events have provided the program office with visible benchmarks upon which future SLEP ships have been measured.

USS FORRESTAL (CV59), the second ship to commence SLEP, started her industrial availability at PNSY on 21 January 1983. The FORRESTAL SLEP incorporated numerous lessons learned during the planning and execution phases of the SARATOGA SLEP [18]. They were:

- Spare FORRESTAL main engine turbine rotors were overhauled prior to commencement of FORRESTAL SLEP. This was a result of delays experienced in the ma'n propulsion overhaul of SARATOGA.
- Early hydrostatic test of through tank piping to improve schedule adherence.
- Up front manning for structural repairs in catapult troughs.
- Adherence to specified standards of quality and workmanship.
- Established a Boiler Management Team (BMT) to oversee the boiler repair project. All work instructions and procedures related to the boilers were reviewed and approved by NAVSSES and NAVSEA 05 prior to their being issued by PNSY.
- Improved Quality Audit Program (QAP) implemented with NAVSSES reviewing progress in major work areas.
- Pre-Sea Trial Audit (PSTA) program as part of NAVSEA Test and Certification Plan. NAVSEA chairs and audits critical system readiness for commencement of sea trials.
- Ship's Installation Assurance Test (SIAT) for special weapons and non-nuclear weapon installation and support readiness.
- In-Process Review (IPR) chaired by NAVSEA and conducted by NAVSSES for selected items of interest.

Pre-availability testing accomplished in FORRESTAL disclosed that FORRESTAL entered SLEP in a worse overall material condition than SARATOGA and would require increased effort and funding to restore the ship to a serviceable condition. Catapult components showed massive corrosion and required extensive renovation to return these systems to "like new" condition. The breakdown of mandays for the FORRESTAL SLEP was 1.168 million mandays for repairs and 0.432 million mandays for ship alterations, for a total of 1.6 million mandays.

Due to the extensive work planned in catapult components, USS FORRESTAL, while in Mayport from 16 November 1982 to 18 January 1983, began a pre-SLEP availability. The work consisted of asbestos removal from catapult steam systems, open and inspect and removal of equipment from launch and recovery systems, laser alignment, and preparation of access cuts. Approximately 240 workers from PNSY, including design, planning and estimating, and production were in Mayport.

For comparison purposes, SARATOGA's reserves at the start of availability were approximately 20 percent. FORRESTAL's reserves at the start of availability was approximately 17.5 percent. Though there was a larger percentage in reserves for SARATOGA SLEP, many areas of growth in SARATOGA's SLEP, which were funded out of the program manager's reserves were included in FORRESTAL as authorized work items in the SARP.

In all aspects, USS FORRESTAL SLEP was highly successful. The INSURV Underway Trial for CV 59 was held 15 to 19 April 1985. Her PSA/SRA was from 13 September 1985 to 18 December 1985. One significant problem encountered in the CV 59 SLEP was a problem experienced in #3 main reduction gear. During the Underway Trial, babbit was found in the main lube oil strainer of #3 main engine during routine inspection. After an inspection of all bearings in #3 main reduction gear, it was discovered that all bearings showed signs of tin oxide. The presence of tin oxide is dependent upon having water in the lube oil at elevated temperatures, such as would be found during engine operation. It became apparent that the tin oxide on the main reduction gear bearings of #3 main engine was formed prior to SLEP. During her SLEP, USS FORRESTAL main reduction gear bearings were not overhauled nor were they planned to be overhauled. USS FORRESTAL sailed on schedule on 20 May 1985, her SLEP delivery date, with #3 shaft uncoupled and trailing. Repairs to #3 main reduction gear were executed during CV 59 PSA at Mayport, using personnel from SUPHSIP Jacksonville and contractor services. The decision to have the repairs executed in Mayport vice Philadelphia was based upon the Navy's belief that it presented the best compromise between a fully capable ship and the need to get the ship into her workup cycle and out of the shipyard [19].

After USS FORRESTAL's INSURV Underway Trial, the Navy was wrestling with the comments of President Board of Inspection and Survey (PRESINSURV) who agreed that though SARATOGA and FORRESTAL met the stated CNO objectives of SLEP, he emphatically stated that the ships did not meet INSURV complete ship criteria, namely, a ship properly preserved, painted out, and ready for service. The position NAVSEA presented to the CNO was, if we are to meet the PRESINSURV's complete ship criteria, we must redefine SLEP objectives and provide additional funding to do so. The initial engineering studies conducted by NAVSEA indicated that approximately 10,000 mandays were required for the correction of electrical discrepancies, 45,000 mandays were required for ventilation and interior communication restoration, 31,000 mandays to restore fumetight and watertight integrity and 72,000 mandays for the preservation and habitability upgrades required to more closely approach the INSURV complete ship requirements.

USS INDEPENDENCE (CV 62), the third carrier to undergo SLEP, entered PNSY to commence SLEP on 18 April 1985. Shortly after commencing SLEP on 18 April 1985, CNO in a letter dated 18 June 1985 directed that USS INDEPENDENCE SLEP be planned for 37 months duration, from its originally scheduled 28 months, to complete 18 May 1988. To improve productivity during USS INDEPENDENCE 37 month SLEP, PNSY instituted the following initiatives:

- Improved production/test sequencing due to the stretched out schedule.
- Production department reorganization.
- Team concept for major repair and alteration projects.
- Early fixed pricing.
- Emphasis on early design freeze.
- Reduction in premium pay (overtime, backshift).
- Improved integration of ship's force work package.

The INSURV Underway Trial for CV 62 was held 28 March 1988 to 1 April 1988. USS INDEPENDENCE was officially reintroduced to the fleet on 16 May 1988. PRESINSURV reported that CV 62 material condition was markedly improved over previous SLEP ships. USS INDEPENDENCE PSA occurred from 8 November 1988 to 3 March 1989 at North Island Naval Air Station San Diego, California.

USS KITTY HAWK SLEP was hampered by numerous changes to the work package during both the advance planning and execution phases of her SLEP. As mentioned previously MSP and HE were initially studied for inclusion into the USS KITTY HAWK FY88 SLEP. These two alternations were subsequently canceled from CV 63 SLEP in February 1988 and January 1987, respectively. The cancellation of MSP and HE from the CV 63 SLEP work package required a large number of ship alterations be added to the work package to make up for the mandays ($100 million) initially reserved to improve the survivability of CV 63. These ship alterations, which initially numbered 11, became known as the Alternative Vulnerability Reduction Program (AVRP). Eventually these 11 alterations were reduced to 10 alterations due to the immense impact, both in cost and schedule, that the Island Fragmentation Protection ship alteration had on CV 63 SLEP. Table 1 list these 10 additional ship alterations for CV 63 SLEP.

Philadelphia Naval Shipyard, in preparation for USS KITTY HAWK SLEP instituted the following initiatives to improve productivity and to reduce cost:

- Zone technology approach in approximately 30% of the work package.
- Material kitting.
- Line heating.
- Photogrammetry.
- CAD/CAM upgrade.
- Implementation of cost and schedule control system.

On 20 October 1988, the CNO Global Scheduling Conference removed USS RANGER (CV 61) from CV SLEP.

CURRENT STATUS

USS KITTY HAWK (CV63), the fourth carrier to undergo SLEP, entered PNSY to commence SLEP on 28 January 1988. USS KITTY HAWK is currently approximately 75 percent completed with her 1.73 million manday, 37 month SLEP availability. CV 63 is scheduled to complete SLEP on 28 February 1991 and commence her post shakedown availability (PSA) in Philadelphia on 3 June 1991 until 31 August 1991. USS KITTY HAWK is currently scheduled to be homeported in Pensacola, Florida upon completion of her PSA.

USS CONSTELLATION (CV64), the fifth carrier scheduled to undergo SLEP is currently in Philadelphia Naval Shipyard for a pre-SLEP restricted availability. CV 64 entered PNSY in mid-April 1990 and is scheduled to commence a "reduced scope" SLEP of 1.1 million mandays and 29 months duration. This funding level will support the primary SLEP objective of extending the life of the ship by 15 years through core engineering and flight deck repairs and modernizations. However, this funding level will not support the historic levels of repairs and habitability improvements of previous SLEP ships. Approximately 300,000 mandays of repairs and habitability work alone, have been cut from CONSTELLATION work package. This implies that all deferred maintenance and modernization improvements will be factored into future availability planning by the Type Commander for CONSTELLATION. The length of CV 64 SLEP was planned for 28 months. However, in January 1990, the CNO directed restoration of 4 war fighting ship alterations in CV 64 work package which caused a change in delivery of one month to 5 December 1992 [20, 21]. The CV 64 PSA is scheduled for San Diego, California in mid 1993.

Table 2 provides a SLEP funding comparison of all SLEP carriers. It is noteworthy to see how significant government furnished equipment (GFE) expenditures increased over the first four SLEP carriers as the complexity of the included alterations changed over time. The primary reason for the reduced GFE expenditure for CONSTELLATION compared to KITTY HAWK is the "reduced scope" SLEP concept for CONSTELLATION SLEP. For comparison purposes, KITTY HAWK SLEP work package included approximately 170 ship alterations, while CONSTELLATION SLEP work package included only 70 ship alterations.

Table 3 provides a comparison of the more significant ship alterations that have been executed and planned for the first five SLEP carriers. Again, after a quick glance of Table 3, one can conclude that the first four SLEP carrier's modernization work package during SLEP was significantly greater that the "reduced scope" SLEP scheduled for CONSTELLATION.

FUTURE OF SLEP

The future of the CV SLEP Program is uncertain and subject to change. It is likely that the budget constraints imposed by Congress on the Department of Defense will dictate the aircraft carrier force levels that can be supported, which in turn will determine the need and future of the CV SLEP Program. All advance planning studies have been reduced to a minimum to support only those functions which make good economic sense and are critical in preserving the option to execute future SLEPs. Table 4 illustrates the current funding for CV SLEP in the FY90 and FY91 defense budget. In FY90, USS CONSTELLATION SLEP received the balance SLEP funding.

SUMMARY

The aircraft carrier continues to be a vital component of the force structure of the United States Navy. To support the aircraft carrier force levels required in the 21st century, the CV SLEP Program was established in 1976 to extend the life of selected aircraft carriers for 15 years through an extensive overhaul of designated ship alterations and repairs to core engineering and flight deck systems. Three aircraft carriers have completed SLEP, one is currently in SLEP, and three more carriers are planned to commence SLEP in the future. The outstanding post SLEP performance of the first three SLEP aircraft carriers demonstrate the success achieved by the CV SLEP Program and is the most significant characteristic ensuring continuation of CV SLEP Program as scheduled.

Acknowledgment

The author wishes to express his gratitude to his predecessors as the Assistant Program Manager for CV SLEP. Their meticulous notes, reports and presentations formed the basis for the work presented herein. In particular, the support and assistance by Captain Frank C. Holmes, USN, the Aircraft Carrier Program Manager, is gratefully acknowledged.

BIBLIOGRAPHY/REFERENCES

[1] Chief of Naval Operations Letter Serial 00/500807 dated 13 March 1976.

[2] Chief of Naval Operations Executive Board Decision Memorandum dated 4 April 1977.

[3] OPNAVINST 4700.34A, Aircraft Carrier Service Life Extension Program (CV SLEP) Management Plan of 6 December 1982.

[4] Chief of Naval Operations Message 242225Z April 1978.

[5] Assistant Chief of Naval Operations (Air Warfare) Point Paper dated 1 September 1978.

[6] Commander, Naval Sea Systems Command Letter PMS392E3/BC, Serial 361 of 15 June 1982 endorsed by Chief of Naval Material.

[7] Assistant Chief of Naval Operations (Air Warfare) Memorandum dated 15 July 1982.

[8] Chief of Naval Operation Letter Serial 00/300289 dated 15 July 1982.

[9] Holmes, F. C. Captain, USN Brief Sheet dated 29 February 1984.

[10] Pyatt, Everett, Assistant Se retary of the Navy (Shipbuilding and Logistics) Memorandum dated 1 February 1985.

[11] Lehman, John, Secretary of the Navy, Letter dated 25 November 1985.

[12] Lehman, John, Secretary of the Navy, Letter dated 16 July 1985.

[13] Commander, Naval Sea Systems Command Letter 4186 Serial PMS392C/1120 of 31 August 1984.

[14] Commander, Naval Sea Systems Command Letter 4710 Serial PMS392CB/1182 of 23 September 1985.

[15] Commander, Naval Sea Systems Command Letter 4700 Serial 00/1783 of 17 December 1989

[16] Chief of Naval Operations Letter Serial 551D/8U596243 dated 19 February 1988.

[17] Mares, D.L. Captain USN Point Paper dated 7 June 1983.

[18] Mares, D.L. Captain USN Point Paper dated 3 February 1982.

[19] Chief of Naval Operations Letter Serial 00/5U30020 dated 23 May 1985.

[20] Chief of Naval Operations Letter Serial 551D/9U596418 dated 13 September 1989.

[21] Chief of Naval Operations Letter Serial 551D/9U596456 dated 4 January 1990.

Table 1 - AVRP SHIPALTS for CV 63

6300	LIST CONTROL
6667	AN / WLR - 1H ESM
6833	AN / SXQ - 8 (V) 6
7198	AN / SLQ - 25 EC - 16
7253	AN / SLQ - 32
7286	CIWS Blk 1 UPGRADE
7516	EMERGENCY ORDNANCE HANDLING
7535	RIGID INFLATABLE BOAT
7610	INSTALL 4th CIWS
XX90	UPGRADE TERRIER SPONSON

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Table 2 - SLEP Funding Comparisons
($ in Millions)

SHIP	EXECUTION YEAR	MANDAYS	THEN-YEAR END COST	FY 81 CONSTANT DOLLARS	GFE COST
SARATOGA	FY 81	1,650,000	548.4	548.4	52.8
FORRESTAL	FY 83	1,864,000	695.4	650.3	70.0
INDEPENDENCE	FY 85	1,740,000	829.0	725.7	127.9
KITTY HAWK	FY 88	1,730,000	946.9	733.7	175.7
CONSTELLATION	FY 90	1,100,000	750.0	539.6	160.5

Table 3 - Major SLEP Alterations Matrix

	60	59	62	63	64
CATAPULT WET ACCUMULATORS	X	X	X	X	X
MK-7 MOD 3 ARRESTING GEAR	X	X	X	X	X
ROTARY LAUNCH VALVES	X	X	X		
LENGTHEN CAT #4	X	X			
FLIGHT DECK EXTENSION	X	X	X		
ROTARY RETRACT ENGINES				X	X
MK II FLUSH-DECK NOSE GEAR LAUNCH			X	X	
INSTALL 3RD MK-7 JET BLAST DEFLECTOR				X	X
F-14 SUPPORT		X			
F-18 SUPPORT			X	X	
NATO SEASPARROW	X	X	X		
CIWS	X		X	X	X
CIWS MAINTENANCE ENCLOSURE				X	
IMPROVED WEAPONS STOWAGE	X	X	X		X
STRAIGHT-THRU WEAPONS ELEVATOR	X	X			

Table 3 (Cont.) - Major SLEP Alterations Matrix

	60	59	62	63	64
UPGRADE CVNS (SINS IMPROVEMENT)				X	X
SINGLE AUDIO SYSTEM	X	X	X	X	
AN/SPN-46 A/C LANDING SYSTEM				X	X
AN/SPS-49 LONG RANGE AIR SEARCH	X	X	X		
AN/SPS-49 (V)5 AIR SEARCH RADAR				X	X
TASK FORCE COMMAND CENTER PHASE I		X	X		
TASK FORCE COMMAND CENTER PHASE II				X	X
TARGET ACQUISITION SYSTEM MK-23			X	X	X
AN/SYS-2 (CV) IADT MODS				X	X
NTDS UPGRADE			X	X	X
AN/SLQ-32 (V)4				X	X
AN/SPS-48E 3-D RADAR				X	X
INCREASE AIR CONDITIONING	X	X	X	X	X
REPLACE MOTOR DRIVEN FIRE PUMPS	X	X	X		
REPLACE SSTG TURBINE CASINGS				X	

Table 3 (Cont.) - Major SLEP Alterations Matrix

	60	59	62	63	64
H.P. AIR COMPRESSOR	X	X		X	
HALON MACHINERY SPACE	X	X			
HALON PUMP ROOM			X	X	X
INSTALL LARGER DISTILLING PLANTS	X	X			
L.P. O_2N_2 PLANT	X				
DRY BILGE SYSTEM	X				
CHT	X			X	
MAG SPKLG DEFICIENCIES	X				
REPLACE JP-5 FUEL/DEFUEL SYSTEM		X	X		
AFFF RESERVE & TRANSFER		X	X		X
LIST CONTROL				X	
REPLACE MAIN FEED PUMPS				X	
IMPROVE ELECTRICAL DISTRIBUTION				X	X
COMMISSARY UPGRADE	X	X	X		
MEDICAL/DENTAL IMPROVEMENTS	X	X	X	X	

Table 4 - FY 90 / 91 SLEP Budget
($ in Millions)

		FY 90	FY 91
KITTY HAWK	(OUTFITTING)	13.8	3.6
	(POST DELIVERY)	0	20.5
KENNEDY	(ADVANCE PROC)	0	113.1
CONSTELLATION	(OUTFITTING)	13.0	13.8
	(BALANCE FUND)	643.3	0
TOTAL		670.1	151.0

Design/Maintenance Interface: A Key To Naval Shipyard Performance

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ABSTRACT

Naval Shipyards are implementing Total Quality Management (TQM) principles and tools as they strive for excellence in ship maintenance. One key initiative in this effort is continuous improvement in the design/maintenance interface. The objective of this initiative is to ensure that technical design engineering decisions take into account naval shipyard industrial process efficiency and facility capability considerations, with goals to minimize maintenance costs and schedule durations without compromising quality.

Producibility, which focuses on minimizing ship construction costs, is currently the subject of much needed attention in the NAVSEA community. Maintainability is an equally important and directly related consideration. Maintainability refers to any concept or action that reduces ship overhaul and repair cost without any degradation of performance. The concept of "design for maintenance" is at the heart of the naval shipyard design/maintenance interface. This paper examines the concept and principles of maintainability, and describes existing and proposed naval ship design/maintenance interface initiatives, such as specification reviews and hazardous material reduction. Examples of successful design/maintenance interface actions are also presented.

THE ISSUE

Too frequently, design engineering and production engineering functions are treated as a linear process. Design engineers do their required work and pass it on to logisticians, who, at the proper time, pass it to production engineers at the overhaul depot when scheduled. In our view, this concept of linear flow is wrong. Here, common ground needs to be established so that the design/maintenance and logistics functions are performed concurrently and cooperatively to ensure maximum effectiveness. Technical decisions having cost and schedule impact on ships are made by technical authorities outside the shipyard with only indirect cost or schedule responsibility for shipwork. If the naval shipyards are to achieve expected cost efficiencies, Industrial Engineering must act as a strong bridge between ship system design and production engineering in order to get maintenance planners involved in those technical decisions which are close to shipwork methods or industrial processes.

Investigation shows (during a review of ship design for maintainability in 1984) that the design and production engineering groups at NAVSEA corporate and field commands do not have a sufficiently close or coorperative relationship. This is unfortunate because the two groups working together hold the potential to make significant contributions to productivity throughout the Integrated Logistics Support process.

Increasingly complex ship systems, proposed reductions in outyear DOD budgets, and changing fleet maintenance strategies serve to highlight the need for strong, cohesive, directed advanced industrial capacity plans for executing depot level repairs and overhauls to support the ILS process. The people that design shipboard systems need to interface more closely with the people who are required to fix them.

BACKGROUND

The concept of maintainability applies to all aspects of the ship design and maintenance process, from the hull design to the overhaul work package definition, from the quality of drawings to the material requirement specifications, and from capital investments required for shipalt

capability to the response time for technical requirements waiver requests.

Like producibility, maintainability is but one factor in the equation for consideration in ship and ship system design and specifications. However, given the significant amount of total ship life cycle time and cost incurred by overhaul and repair, the potential savings increased operational time make the design/maintenance interface a critical target of opportunity. This fact is recognized and illustrated by two innovations which are currently having unprecedented impact on the naval shipyard design/maintenance interface.

The first, Computer Aided Design/Computer Aided Manufacturing (or maintenance CAD/CAM) automates the design/maintenance interface. The second, Zone Technology, is bringing about changes in design products to better fit maintenance strategies. SEA 07 has initiated several other improvements to augment the design/maintenance interface.

In September 1984 NAVSEA 070 established a working interface between naval shipyard production and design engineering to review proposed design changes to determine cost and impact. In 1986 NAVSEA 07 initiated a study of design for maintainability that focused on the aircraft carrier hull expansion program. The study revealed the need for establishing and maintaining working relationships between technical design engineering and production engineering at all levels of ILS planning to direct and control depot level industrial support requirements.

Early in 1987, SEA 07 presented Design/Maintenance Interface issues at the shipyard commanders conference and followed-up in May 1987 with a letter to all shipyards. The letter formally initiated action to establish optimum working interfaces between existing industrial and design engineering organizations, while emphasizing that the two organizations are vital to shipyard performance and productivity improvement. The role of industrial engineering in naval shipyards is to develop and implement the most cost effective industrial processes for preforming ship overhaul/repairs, but these processes must not violate technical requirements, although specification streamlining is always a consideration.

During this period, NAVSEA 07 also initiated reviews of specifications, drawings, standards, and handbooks through participation as a member of the the NAVSEA Specifications Control Board. Review of Integrated Logistics Support Plans also became a normal part of the SEA 07 operation. Representatives from Sea 07 also participated in the NAVSEA 1989 producibility workshop.

The objective is to optimize the application of industrial engineering (IE) principles and techniques in the Naval Shipyards in order to continuously improve on shipyard cost, schedule, and quality performance. To achieve this through TQM, the Design/Maintenance Interface initiative simply emphasizes "TEAMWORK" between the people that design systems and equipment and the people that are required to "fix" them at the depot level.

DESIGN/MAINTENANCE INTERFACE

Process analysis is part of both strategic planning and technical production engineering. The basis for process analysis is the planning unit, which is the central entity around which production engineering and planning work is organized. These are defined by production engineers who determine the work to be done at each stage of production. Process analysis aids in planning, controlling, and monitoring production work. The work must be broken down into discrete work packages, where each work package will define the specific amount of work to be done at a particular stage of production. This is done by production engineers who decide upon the sequence of work to complete the planning unit in the required time, and to the required quality. To be effective, production and design must be involved in process analysis.

Through process analysis during the design phase, requirements for new or additional shipyard resources would be identified with sufficient lead time to phase shipyard budgets with appropriations. The object of a concurrent effort between production and design is to produce a coordinated information package generated from the process analysis that addresses every stage of the production process right through the completion of assigned work. The final products of this effort will be formalized directions for work packaging and work instructions that include the flow process for material, dimensional data and the work method.

The Integrated Logistics Support Analysis (LSA) integrates logistics considerations with the system/equipment design process. Design/Maintenance Interface proposes to expand the LSA to include process analysis for transmitting maintainability information, thus using the LSA as the vehicle for ensuring life cycle support responsibilities from inception to retirement (cradle to grave) of the system or equipment.

The Design/Maintenance Interface organization shall be staffed with industrial engineers, engineers from the technical design community and specialist with a broad background in day-to-day depot level industrial operations, must function to conduct depot level impact assessments of:

Propulsion
Hulls and Structures
Combat Systems/Electronics
Auxiliary Equipment

Reviews must be conducted of acquisition plans, technical and acquisition specifications and all aggregations of integrated logistics support including information from the maintenance material management (3M) data bank.

SPECIFICATION CONTROL BOARD

The Specification Control Board functions to ensure that proper assessments of new or revised specifications standards, handbooks, and drawings is made prior to board approval, and that implementation guidance is provided when needed. The board membership currently consist of representatives of the Fleet Maintenance Officers, NAVSEA technical design engineering, logisticians and maintenance planning communities. Previously NAVSEA 07, as a non-voting member received the results of the board actions but had no input prior to approval.

The purpose of NAVSEA 07 participation is to ensure that proper consideration is given to Naval Shipyard cost and operations during the specification review cycle. In addition, the NAVSEA Industrial Engineering and Planning Division is acting as the bridge between the technical design community at headquarters and the naval shipyard design/maintenance effort.

Because of this relationship, we were able to assist naval shipyards in resolving problems with specifications that impacted the execution of normal work and maintenance. NAVSEA 07 was able to have representatives from ASTM/ANSI and the NAVSEA technical design community deal directly with shipyard production engineering representatives to resolve technical and acquisition specification issues. Specific issues included revising power piping codes, resolving aircraft carrier weapons elevator braking problems, ensuring proper EPA standard application for cleaning main and auxiliary boilers with hydrochloric acid, revising procurement specifications for scaffolding to improve strength testing and first article inspection criteria among many others.

Advances in technology, increased effectiveness, and many other factors have been advanced as reasons for changing existing specifications or for issuing new ones. Every specification is issued or changed only on the basis of a thorough engineering analysis.

Frequently, in attempting to satisfy an immediate technical problem with a specification change, an objective assessment of the impact of the change on all phases of current and future acquisitions, maintenance, training packages, and facilities is overlooked. This analysis should considers the total impact, cost effectiveness, extent of applicability, standardization, and the impact on maintenance philosophy. An initiative is underway in NAVSEA 05 to implement TQM in this area through the specification standardization process.

UNIFORM INDUSTRIAL PROCESS INSTRUCTIONS

Naval Shipyards are expanding the application of industrial engineering tools and techniques to identify, evaluate, and implement production methods and industrial process improvements.

These methods/processes are the "how to" that the shipyard applies to achieve the technically specified end product. In order to fully document these process improvements so that they can be exported and implemented by all naval shipyards, Uniform Industrial Process Instructions (UIPIs) are issued.

UIPI's identify the equipment, materials, safety, environmental, quality assurance, skills, and the step-by-step method required to perform the most efficient and effective process to get the job done. Technical specifications are also integrated in the UIPI so that the document provides all the information needed for the shipyards to plan, implement, and control the process. Design engineering approval is required for each UIPI, thereby making the document a key building block in the design/maintenance interface.

One noteworthy example of how this element of the interface works was demonstrated in the development and implementation (and continuous improvement) of the Special Hull Treatment Installation UIPI.

HAZARDOUS MATERIAL REDUCTION

Another area of the design/maintenance interface that is growing exponentially in importance and visibility is in hazardous waste minimization (HWM). The naval shipyards have implemented an aggressive HWM program which focuses on eliminating the generation of hazardous waste at the source. This program is consistent with DOD and DON policy and priorities, including a goal to reduce HW generation by 50% by 1992.

Hazardous waste is generated as a by-product of the industrial processes applied for ship overhaul and repair. A significant amount of this hazardous waste is generated as a result of hazardous materials used as ingredients in the industrial process. Often, hazardous

materials are required by the applicable technical engineering documents/specifications.

In order to minimize HW, material substitutions and process changes may be required, and are predicated on a change to the technical document. A threefold approach is required with a close working interface between production and design engineering, as follows:

a) In the shipyard's current HWM program, requests for material substitutions are submitted on a case basis for specific, existing technical documents as part of a given HWM process analysis. NAVSEA must be responsive to these requests.

b) As new technical documents are being developed, minimizing the hazardous materials specified must be an important consideration of the development process.

This "front end" approach is vital, and all design engineers must have heightened awareness of and sensitivity to keeping hazardous materials out of technical documents.

c) A major effort is required to review all existing issued technical documents to identify and implement opportunities for substituting non-hazardous or less hazardous materials in products and process.

SUMMARY AND CONCLUSION

Improvements in working relationships between technical design engineering and production engineering is essential to ensure that technical design decisions take into account process efficiency, facility capacity and capability with the objective of minimizing production cost and capital investments without compromising technical requirements. Current industrial improvement program initiatives, combined with the need for naval shipyards to become more cost efficient and to compete successfully with the private sector, dictates the need to establish improved design/maintenance working relationships in order to facilitate the expected cost efficiencies.

Accordingly, concurrent review of pre-construction designs, and programs such as Integrated Logistics Support Plans, and the Material Maintenance Management (3M) System along with review of alterations, specifications and Standards must become the basis for planning future long range depot level maintenance strategy.

The aim is to establish and standardize an information transfer system at all levels of maintenance addressing Hulls and Structures, Propulsion, Combat Systems/Electronics, and auxiliary Equipment.

The purpose of this paper as outlined, is to describes the system of review of designs and modifications to major weapon systems to allow for the early identification of investment requirements in naval shipyards. Likewise the system must provide input to acquisition managers, and system designers with respect to shipyard capability and capacity so that appropriate consideration is given to these factors in the design process.

REFERENCE DOCUMENTS

NAVSEA 070 Letter 11000, Serial 0704/104, Dated 13 September 1984. Subj: Naval Shipyard Interface with Preliminary Ship Design

1985 Coopers and Lybrand Study; Shipyard Review Report

NAVSEA 07 Memorandum 5240, Serial 0704/84, dated 3 April 1986. Subj: Industrial Engineering

NAVSEA 07 Study, July 1986. Subj: Review Of Maintainability Feedback for Ship Design

NAVSEA 07 Letter 4710, OPR: 07011, Serial 07/029, dated 10 March 1987. Subj: SSN 688 Class Submarine Recyclable Package Program Policy

NAVSEA 07 Memorandum 4732, OPR:07011, Serial 07/025, Dated 8 May 1987. Subj: Ship Design/Maintenance Interface

NAVSEA 07 Letter 5240, OPR: 07011, Serial 07/056, dated 8 May 1987. Subj: Industrial Engineering Interface with Design Engineering

NAVSEA 07 Letter 4710, OPR: 0701, Serial 07/007, dated 2 February 1988. Subj: Internal Rotatable Pool Program Policy

NAVSEA LETTER 4780, OPR: 07011, Serial 07/279, dated 20 October 1988. Subj: NAVSEA Specification Control Board

NAVSEA Instruction 4121.3. Functions, Organization and Operating Procedures for NAVSEA Specifications Control Board

OPNAV Instruction 4790.2D Volume V. Maintenance and Material Management Manual

NAVSEA Instruction 5240.2. Management Control System for Industrial Processes in the Naval Shipyard.

DOD Directive 5000.39, Acquisition and Management of Integrated Logistics Support for Systems and Equipment

MIL-STD 13881A. Logistics Support Analysis (LSA)

MIL-STD 13882A. Logistics Support Analysis Record (LSAR)

NAVSEA Instruction 4720.16. Logistics Management Procedures for Configuration Changes Installed Outside of Depot Level Availabilities

OPNAVNOTE 5090. DON Goal To Reduce Hazardous Waste Generation By 50% by 1992

OPNAV Instruction 4110.2. Hazardous Material Control and Management

Production Engineering Magazine June 1987. Partners for Productivity, by Charles F Myers

SURFACE SHIP MAINTENANCE DIVISION AT NAVSEA

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The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense of the Department of the Navy.

ABSTRACT

The paper to be presented at the ASE technical symposium will briefly discuss the purpose of establishing the Surface Ship maintenance Division (SSMD) in NAVSEA. It will provide a broad overview of the SSMD charter, it's organizational structure and it's responsibilities as detailed in NAVSEANOTE 5400. It will then provide information of current initiatives in the SSMD under the Surface Ship Maintenance Improvement Program (MIP). The initiatives to be discussed in detail are as follows:

a) Propulsion Plant Condition Assessment System (PPCAS)
b) Availability Planning Improvement Program (APIP)
c) Maintenance Strategy Cost Estimate
d) Maintenance Technology Survey

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INTRODUCTION

With the disestablishment of OPNAV's OP-43 and NAVSEA's PMS-306 in mid 1980s, the surface ship maintenance community in general, not only lost its advocates in the Pentagon on maintenance related issues, but it also lost a single focal point for providing guidance and direction in formulating maintenance policies and strategies. The budget realities of 80's and the goal of 600 Ship Navy required that the Navy explore innovative and effective methods for maintaining operational readiness of its fleet.

The strategic plan for the Naval Sea Systems Command dated 1 July 1987 identified NAVSEA's intent to improve surface ship maintenance policies and practices in response to changing circumstances and reduced resources. It identified the need:

i) To investigate the desirability of establishing a consolidated maintenance policy and improvement office in NAVSEA

ii) To evaluate alternate surface ship maintenance strategies that emphasize extended operating cycles and shorter periods in shipyard maintenance; and

iii) Increasing requirements to reduce costs of surface ship maintenance to levels clearly defendable by objective cost-effective considerations.

SURFACE SHIP MAINTENANCE DIVISION (SSMD)

The joint SEA 91 and SEA 93 Study Group Report on a Surface Ship Maintenance organization dated 18 September 1987 recommended establishment of a single office to:

- Provide organization and resources for execution of maintenance systems assessment, development, and improvement.

- Establish a NAVSEA-TYCOM partnership in formulating surface ship maintenance policies, and in

developing and testing alternative maintenance practices.

The memorandum of agreement between SEA 91 and SEA 93 dated 4 December 1987 documents an agreement to create a Surface Ship Maintenance organization and provided the initial basis for establishment, its roles and functions, its chain of command, and its budget/financial responsibilities. Task areas assigned to SSMD included:

- Control and technical direction of surface PERAs (Planning and Alterations for Repair and Alterations).
- Assessment of Class maintenance Plans (CMP) policy with utility of current CMPs.
- Sponsorship of maintenance Research and Development (R&D) initiatives.
- Development of standard methodology to formulate and select a class maintenance strategy.
- Development of procedures to effectively export Systems and Equipment Maintenance Monitoring of Surface Ships (SEMMSS) procedures applicable to surface ships.

Among numerous expectations to be realized from creation of this office were:

- Effective and coordinated technology/procedures transfer among PERAs, to include standardization and efficiency in operations.
- Creation of a process for developing a CMP that adheres to principles of Reliability Centered Maintenance (RCM), its integration with other elements of maintenance planning, and which results in a product that will be used in the fleet.
- Co-ordination of maintenance strategy selection for a new ship class.
- Provide a central point of contact for surface ship maintenance policies and maintenance systems initiatives;
- Provide systematic procedures for assessing and managing risk to mission readiness during operating cycles; and
- Provide Reliability Centered Maintenance (RCM) based, disciplined technical systems and resources for preventive and corrective ship maintenance decisions.

The organizational structure of the Surface Ship Maintenance Division (SSMD) as established by the SEA 91 and SEA 93 MOU is as shown in fig. 1. Since its establishment, the SSMD has become the strongest advocate of the RCM in NAVSEA. Though the MOU does not explicitly assign the Maintenance Improvement Program (MIP) to the SSMD, the SSMD inherited this program from the SEA 93 maintenance office. The SSMD organization, over the last couple of years has expanded. Initially, the program management responsibility for the Detection, Action, and Response Techniques (DART) program was assigned to the SSMD. Later, with the disestablishment of PMS-375 in 1988, the Machinery Condition Assessment (MCA) program was transferred to the SSMD. NAVSEANOTE 5400 dated June 89, formalized the expanded role and responsibilities of the SSMD. The scope of SSMD as defined in NAVSEANOTE 5400 encompass the following:

1) Co-ordination within NAVSEA and its reporting activities and with the Fleets and Surface TYCOMs, the assessment, development and improvement of surface ship maintenance policies, systems and procedures.

2) Direct management of specific surface ship maintenance development initiatives.

3) Development and coordination of the application of appropriate surface ship maintenance policies and practices by ship program managers.

SSSMD is directly responsible to both SEA 91 and SEA 93 for successful development of surface ship maintenance policy and procedures. Specific responsibilities currently assigned to SSMD include:

- PERA Management. Provide management control of and technical direction to the surface ship PERA organization.
- Machinery Condition Assessment (MCA). Serve as the Navy's MCA manager and the single office within NAVSEA for MCA program policy and focus. Assume responsibility for coordinating all MCA efforts and for ensuring implementation of a fully coordinated and responsive RCM based MCA program for the fleet.
- Detection, Action, and Response Technique (DART) Programs. Monitor and review progress of all DART programs. Support SEA 91 and SEA 93 in management of DART programs, ensuring quan-

titative measures of progress and problems are developed and implemented.

- Class Maintenance Plans (CMPs). Assume responsibility for CMP policy, procedures and monitoring of implementation, including the update of NAVSEA tech specifications SL790-AC-SPN-010/CMP.

- Reliability Centered Maintenance (RCM). Promote the implementation of RCM - based preventive and corrective maintenance planning in all aspects of surface ship maintenance management. This duty is directed toward both reduction in surface ship maintenance costs and improvements in operational availability.

- Maintenance Research and Development (MR&D). Serve as NAVSEA central point of contact for participation in the maintenance R&D elements of the NAVSEA logistics R&D program. Advocate and promote programs for R&D in the areas of maintenance diagnostics systems, maintenance management, supply support systems and maintenance assessment.

- Maintenance Improvement Program (MIP). Provide for development and implementation of maintenance , material and logistic support policies, procedures, directives and techniques applicable to all surface ship maintenance strategies. The purpose is to improve the effectiveness and efficiency of maintenance requirement determination, maintenance planning and maintenance execution.

The current organizational structure of the SSMD is shown in fig. 2. Under the auspices of the Maintenance Improvement Program (MIP), the SSMD is currently either sponsoring, investigating or implementing a broad range of initiatives for improving surface ship maintenance. This paper discusses the following MIP initiatives:

1) Propulsion Plant Condition Assessment System (PPCAS)
2) Availability Planning Improvement Program (APIP)
3) Maintenance Strategy Cost Assessment
4) SSMD Technology Survey

1) PROPULSION PLANT CONDITION ASSESSMENT SYSTEM (PPCAS)

The inception of PPCAS can be traced back to two prototype installations sponsored by the SSMD to demonstrate the applicability of on line monitoring and diagnostic systems; namely, the Diesel Engine Monitoring & Analysis (DEMA) system and the Fireroom Maintenance Management system (FMMS). The goal was to use commercially available technology in assessing condition of machinery on line, so that an operator could detect abnormal equipment operation and take corrective measures to avert catastrophic failures.

Both DEMA and FMMS have been proven successful and have strong endorsements from the TYCOM. Both DEMA and FMMS use the same basic hardware and operating system. The application software in one case is tailored for a diesel plant and for the steam plant in the other case. The micro processor and the hardware architecture of both systems is such that it has the capability to monitor propulsion plant auxiliary equipment with minor system modifications. Such an installed system can be utilized to it's full potential with a marginal cost increase.

During the evaluation phase of both prototype systems it was evident that technology has a much broader application and the system definition should not link it to a piece of equipment. Therefore, it was decided to broaden the scope of both DEMA and FMMS to include auxiliary machinery and rename it as the Propulsion Plant Condition Assessment (PPCAS) system. PPCAS prototypes are currently being installed on USS WASP(LHD-1) and USS AMERICA(CV-66). A MACHALT proposal to install PPCAS on LSD-41 class has been approved.

The PPCAS system is designed to provide complete machinery condition assessment, diagnostics, prognostics and maintenance management capabilities for a broad range of shipboard machinery. The applications software operates in a multitasking real time environment allowing simultaneous coexistence of foreground/background tasks. The PPCAS provides:

- real time data display of all available monitored parameters

- recall of performance deviation related recorded data

- recall and graphical representation of machinery trend data

- recall and graphical display of expert system based diagnostic advisories related to recommended maintenance actions.

To allow application of the PPCAS to a broad range of shipboard machinery without the need for software modifications, a complex application shell is provided for initial setup and on-line field modifications. All basic functions needed for defining and implementing an

equipment availability management system are provided for in the system editor.

The system consists of a custom computer with a real time multitasking operating system and application software written specifically to perform shipboard machinery condition assessment and availability planning related functions. The components and enclosures have been selected to survive installation in the harsh environment found in marine propulsion/auxiliary spaces. Since the design was focused on the flexibility of application, it can be easily tailored to various ship classes without re-programming or new application program generation. Figures 3 and 4 respectively show a typical PPCAS configuration and data flow diagram.

The system assesses performance and efficiency of machinery, as compared to the design baseline and relationship of the degradation to the operation of the engineering plant. This allows timely planning of the organizational, intermediate and depot level maintenance tasks through isolation of equipment degradations before major effects are realized.

The Top Level System Specifications are as below:

- Real time display of monitored parameters as they relate to expected performance
  - User can request information on any parameter, any subgroup of parameters or all parameters
  - User can design own displays with an editor to best view the data(tabular and graphical)
- Periodic log sheet utilities
  - Automated logging of all parameters onto user predesigned log forms
  - User can use an editor to enter any unmonitored parameters such as lube oil used, filter changes, etc.
  - Comment section for engineer
  - Printing of log forms on wide carriage color printer to allow highlighting of out of limit parameters
- Automated monitoring
  - Individual scan rates for monitored parameters including accelerometers and velocity probes
  - Performance comparison with the baseline curves or alarm values
  - Correlation between two or more parameters with variable performance alarm ranges
  - Triggered scans, where further channels can be checked, data logged and alarms recorded
  - Real time expert based diagnostics, advisories and maintenance recommendations
  - Trending data scans triggered by individual parameters
- Database manager
  - Data transfer to a higher level shipboard and/or shore side computer
  - Flexible database language supported capabilities for data storage and display on demand of performance degradation triggered alarm files and trend files, expert diagnostic files and maintenance management related logistic data file
- Flexible system screen based editor
  - Complete sensor suite definition by channel
  - Individual channel scan rate establishment
  - Identification of scan groups of channels for performance logging
  - Event triggered scan sequence definition
  - Trend data scan group design and periodicity establishment
  - Data formatting for analysis
  - Log form data collection periodicity definition and formatting
  - Tabular and graphical real time performance data display formatting
  - Built in machinery function computing
  - Graphical expert system design input capability for trending diagnostics and maintenance advisories
  - Graphical input of expected equipment performance characteristics
  - Input of logistic management system elements
- Performance baseline establishment
  - Easy graphical and tabular machinery/equipment performance map input facilities

- Trend analysis/ predictive maintenance
  - Knowing baseline conditions of various components, the expert system based diagnostic module will monitor the health of the component continuously over a period of time and allow:

    a) automated scheduling of maintenance actions required in the future, based on analysis of performance degradation

    b) immediate diagnostic advisories
- Reciprocating engine analysis
  - Cylinder cycle efficiency analysis and graphical display and trending
  - Pressure/volume and pressure/crank angle performance assessment trending and display
  - Parameter performance data storage by machine and cylinder for time based comparative analysis
- Maintenance support software
  - Computerized daily, weekly and monthly schedules of activities for engineer supported by expert system based condition analysis of the monitored systems integrated with time directed planned maintenance
  - Interactive mode allows maintenance engineer to enter work performed, conditions found and material used for historical analysis
  - Expert system based diagnostics provides rapid fault identification and corrective action recommendation

2) AVAILABILITY PLANNING IMPROVEMENT PROGRAM (APIP)

During the 1970s and 1980s the Maintenance System Development program (MSDP) was one of the major elements of NAVSEA's PMS-306. The MSDP was conceived as a study of existing ship maintenance policies and procedures and the identification and implementation of more cost effective ones. In 1980, PMS-306 developed the Modified Overhaul Planning Process (MOPP) to apply the principles of Reliability Centered Maintenance (RCM) to the planning of ship maintenance at the depot (d) level. MOPP was tested on eight DDG-2 class ships to determine if their overhauls could be reduced in length without a drop in their Operational Availabilities(Ao). The MOPP was generally a success, however, it did not have sufficient support for it to be institutionalized.

One result of the MOPP test was the development of three manuals for the planning of shipyard availabilities and repair work, which incorporated the MOPP methodology. The maintenance environment has undergone many changes since conclusion of the MOPP program. It was hypothesized that the MOPP methodology could be effectively used in today's maintenance environment if it is correctly reintroduced and is appropriately tailored to meet today's needs. These manuals, however, were deemed to have the following flaws although at the time they represented an excellent pioneering effort:

- They were long and detailed. As a result users may be discouraged from the outset from using them
- They do not include any quantitative risk assessment technique. Risk assessment has become a matter of great interest to the decision makers and sophisticated risk assessment techniques have been developed where their routine application seems feasible with the use of PCs
- Organizations, procedures and terminology have changed sufficiently to make the manuals out dated.

Furthermore the earlier decision logic was never applied solely by civilian and uniformed Naval personnel responsible for the work package development. Instead, manuals were meant for use by specialist in RCM and work package development, who normally assisted the Navy personnel.

In September 1988 the Surface Ship Maintenance Division (SSMD) instituted APIP as the re-examination of the application of the RCM principles to the development of work packages. It has formed a partnership with the Small Craft Repair Facility (SCRF) at the Naval Station, Annapolis, for the purpose of refining and simplifying the repair decision logic and producing the necessary tools for its routine application by Navy personnel.

The two organizations have started a process of the installation, application in an operational situation, and evaluation of revised work package determination procedures based on RCM principles. The test bed for this effort will be the SCRF and the YP 676 class service crafts which it maintains. Appendices A,B and C respectively provide details of repair decision logic, outline of work planning procedures and evaluation procedure for the APIP.

The primary objective of the APIP were to answer four questions:

- Is it feasible to develop and instruct users in a refined, simplified and structured repair decision logic based on RCM principles?

- Is it feasible for Navy personnel now responsible for work package development to apply the logic under normal operating conditions?

- What will be the results of application of this logic?

- Can the product developed during the test be applied generally to all surface combatants, auxiliary and amphibious ships?

Based on these test objectives a plan of action and milestones (POA&M) was established in cooperation with the SCRF. A comprehensive training program was developed. SCRF management, planning staff and YP officers and crew attended these training sessions. From the outset it was obvious that for the process to be successful, active participation from the crew and planning staff was crucial. SSMD has developed PC based programs for risk analysis and for determining the probability of failure for equipment. These programs use a data base that was compiled using historical data available from the SCRF. Tasks 1 through 12, shown in Table 1 have now been completed, and SCRF is now independently using the APIP developed methodology and computer programs to plan YP availabilities.

As the YPs cycle through availabilities, SCRF personnel will collect data that is essential for evaluation. It is estimated that within six to nine months meaningful data would have been collected to compare the cost effectiveness of the APIP.

3) MAINTENANCE STRATEGY COST ESTIMATE

This work responds to the General Accounting Office (GAO) report of June 1988, titled NAVY MAINTENANCE: Ship Maintenance Strategies Need Better Assessment. In that report GAO stated that "the Navy has not developed criteria for moving ships to a particular maintenance program." It recommends that for "each ship the Navy needs to evaluate the mix of overhauls, SRAs or other maintenance availabilities that will achieve the least costly and most timely maintenance strategy for meeting operational needs. For ships that have changed strategies or are being considered for change, cumulative information on how much each maintenance availability costs and how long it takes would enable the Navy to compare maintenance costs and the time a ship was available for operations under earlier and current strategies and perhaps project them for a contemplated strategy. Similarly, consideration of the material condition of the ship while they are available for operations must be evaluated to enable the Navy to compare whether a ship would operate better under a prior, current, or projected maintenance strategy."

The Department of Defense (DoD) addressed these recommendations formally in February 1989 and indicated that the Navy would develop a plan for establishing criteria to evaluate the effects of changes in ship class maintenance strategies. The CNO tasked NAVSEA and SSMD to develop a Standard Maintenance Strategy Selection Methodology.

The objectives of the SSMD tasking are twofold. One is to develop technical and cost criteria that can be used to assess the effects of different maintenance strategies, and the second is to provide an overall picture of surface ship maintenance cost that can be periodically updated.

For the cost model to be useful for the decision makers, the following requirements were deemed to be essential:

a) Comparing maintenance cost for a pair of strategies for existing ships

b) Forecasting the cost of a changed maintenance strategy for an existing ship class. This should include both investment costs and expenses under the new strategy and the cost of the decision making process required to select a preferred maintenance strategy.

c) Forecasting the cost of two or more maintenance strategies for a new ship class.

The process of developing the cost model was separated into seven distinct and identifiable steps. They were:

i) Identifying the elements of cost associated with maintenance and maintenance strategies. This required identifying all costs of a maintenance nature, subdivided by maintenance level (O,I,D, S(special)) and M(management) and between investment and expense items. It then required identifying all non-maintenance costs which are strategy dependent and separating them between investment and expenses.

ii) Identifying sources of historical cost data. These cost data must, where appropriate, be related to systems, hull number, specific availability, and specific strategy. They should also be related to budget and appropriation categories for the future.

iii) Developing algorithms for estimating historical costs. Identifying ship systems which consume the greater share of the depot level maintenance budget and which have predictable maintenance costs, which are different under different maintenance strategies. Identify-

ing in qualitative terms any factors which cause historical costs of maintaining these systems to deviate from 'should cost' values. Using system level data, developing the cost prediction algorithms for the whole ship.

iv) Developing algorithms for forecasting comparative costs for pairs of strategies. Separate sets of algorithms may be needed for existing ship classes and for new ship classes.

v) Test the feasibility of estimating or forecasting strategy-dependent costs for:

- \- an existing ship class for which a maintenance strategy change is contemplated
- \- a new ship class for which two maintenance strategies appear equally satisfactory from a technical and performance standpoint.

It was decided the cost model should be sensitive to variations in the following variables:

- Crew size
- Level of repair of repairable items
- Availability frequency and duration
- Shore management and planning support
- Ship design

vi) Estimate the cost of selecting or recommending a change in maintenance strategy using the methodology described above. This will include costs of estimating or forecasting ship availabilities and strategy- dependent costs as well as executing the methodology.

In conjunction with the cost model, SSMD also developed a technical criteria model as a part of the standard methodology. The technical portion of the methodology was tested initially in ships of the USS WASP (LHD-1) class and in ships of USS NEWPORT (LST-1179) class. It has subsequently been applied independently to ships of the USS KNOX (FF-1052) class and USS SPRUANCE (DD-963) class.

The cost methodology was prototyped on underway replenishment ships as a group, and then was tested on ships of the USS SPRUANCE (DD-963) and USS NEWPORT (LST-1179) classes. Application to the SPRUANCE class was done in conjunction with application of the technical methodology.

The standard methodology for maintenance strategy selection is currently being prepared in NAVSEA technical manual format, and will include criteria to be used to resolve differences between the technical criteria and the cost model.

4) MAINTENANCE TECHNOLOGY SURVEY

The impetus to this task came from the discussion during the Maintenance Symposium held at Virginia Beach, Va in 1987. Many knowledgeable sources from within the Navy and from the industry identified a need to review maintenance problems faced by the fleet and to investigate, if technology exists that can be effectively used to solve these problems without major R&D efforts. In response to this perceived need, the SSMD in conjunction with the Type Commanders and NAVSEA technical community, undertook a four part study designed to provide a focus for cost effective evaluation of existing technologies as they pertain to ship maintenance problems faced by the fleet. The study was divide into four parts:

i) Phase I involved Fleet survey of perceived needs and known technologies. Because the Fleet personnel are in the best position to define maintenance needs, it was the starting point for the interview process.

ii) Phase II involved interviews with NAVSEA and PERA personnel to determine what initiatives are underway or are planned to meet these needs.

iii) Phase III involved interviews of Navy Laboratory personnel and input from Naval Shipyard personnel to obtain more information on technologies of interest. Additionally NAVSUP and NAVAIR personnel were interviewed to identify any common efforts in the area of maintenance technology.

iv) Phase IV consisted of an industry survey to determine the status of technology of interest and to provide analyses of risk and cost/benefit to the Navy.

Over 250 individuals were interviewed to collect information. These individuals were selected from the Navy and commercial maritime community to provide a wide range of insights, from ship operations and hands-on maintenance personnel, to individuals engaged in engineering design, R&D, Navy procurement and commercial product development.

Tables 2 and 3 provide a summary of maintenance needs and the technology that the Navy can adapt to address these needs. In addition to matching technology to maintenance needs, other areas of logistic support that

effect ship maintenance were also identified. We at SSMD recognize this as a continuing effort i.e. to investigate latest technology to solve maintenance needs and have assigned individual responsibilities for continuously seeking out applicable and effective technology for solving today's problems.

REFERENCES

[1] NAVSEANOTE 5400, June 1989

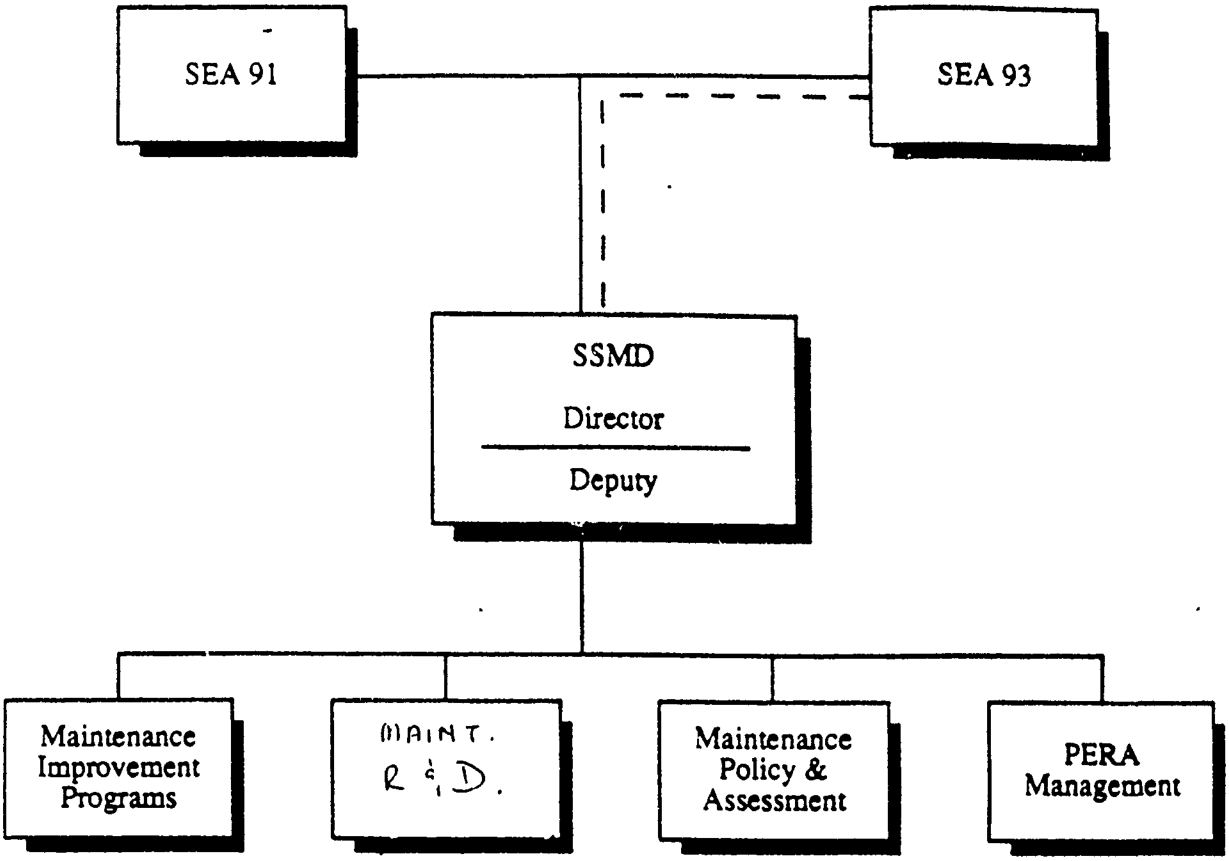
[2] Memorandum of Understanding between SEA 91 and SEA 93 dated Dec 87

[3] Strategic Plan for the Naval Sea Systems command dated July 1987

[4] SSMD report on APIP dtd Sept 89

[5] GAO report titled NAVY MAINTENANCE: Ship Maintenance Strategies Need Better Assessment dated June 1989

Surface Ship Maintenance Division

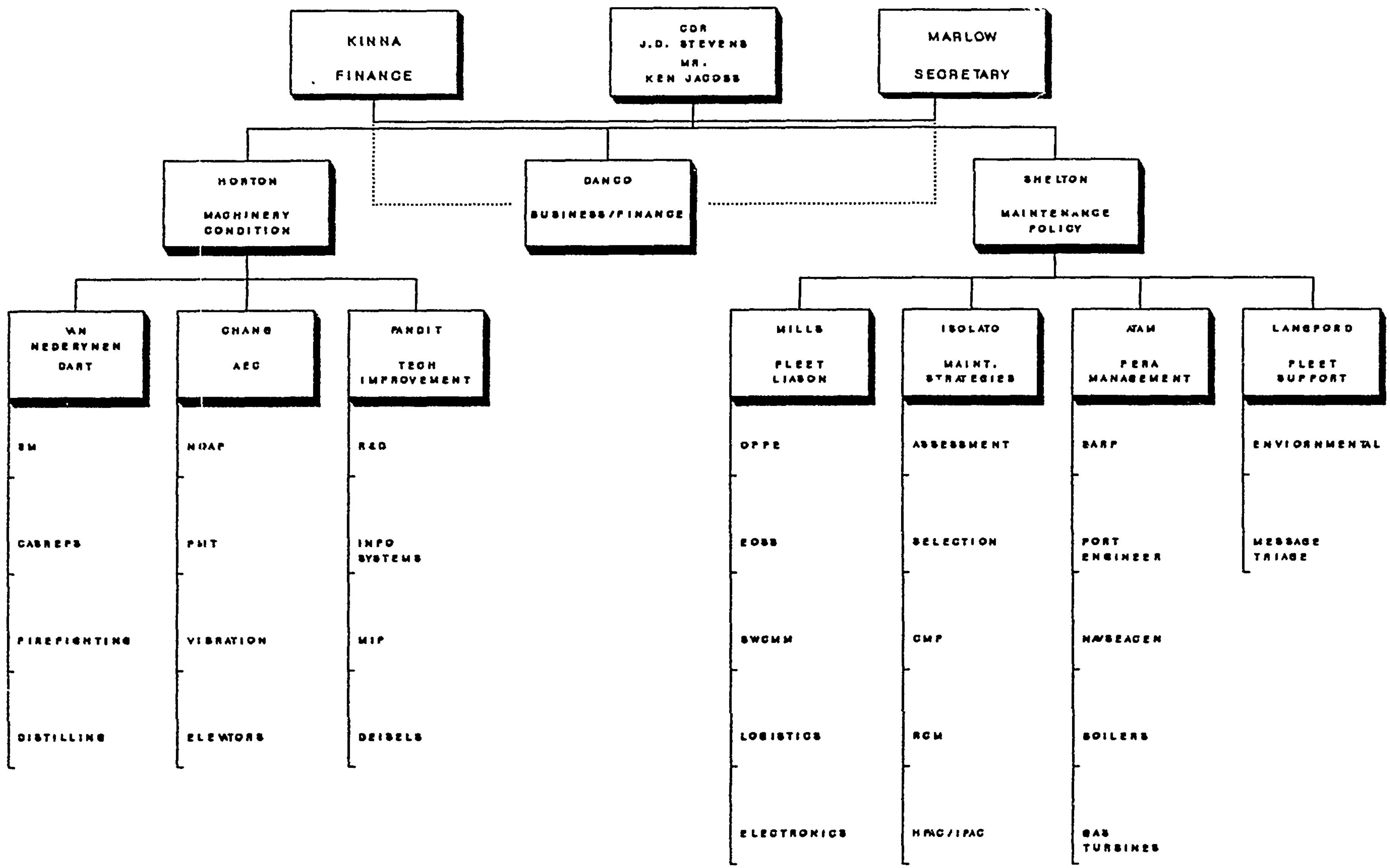


NOTE: — — — — — Administrative Reporting

FIGURE (1)

SURFACE SHIP MAINTENANCE DIVISION

ORGANIZATION CHART



PCAS SHIPBOARD SYSTEM CONFIGURATION

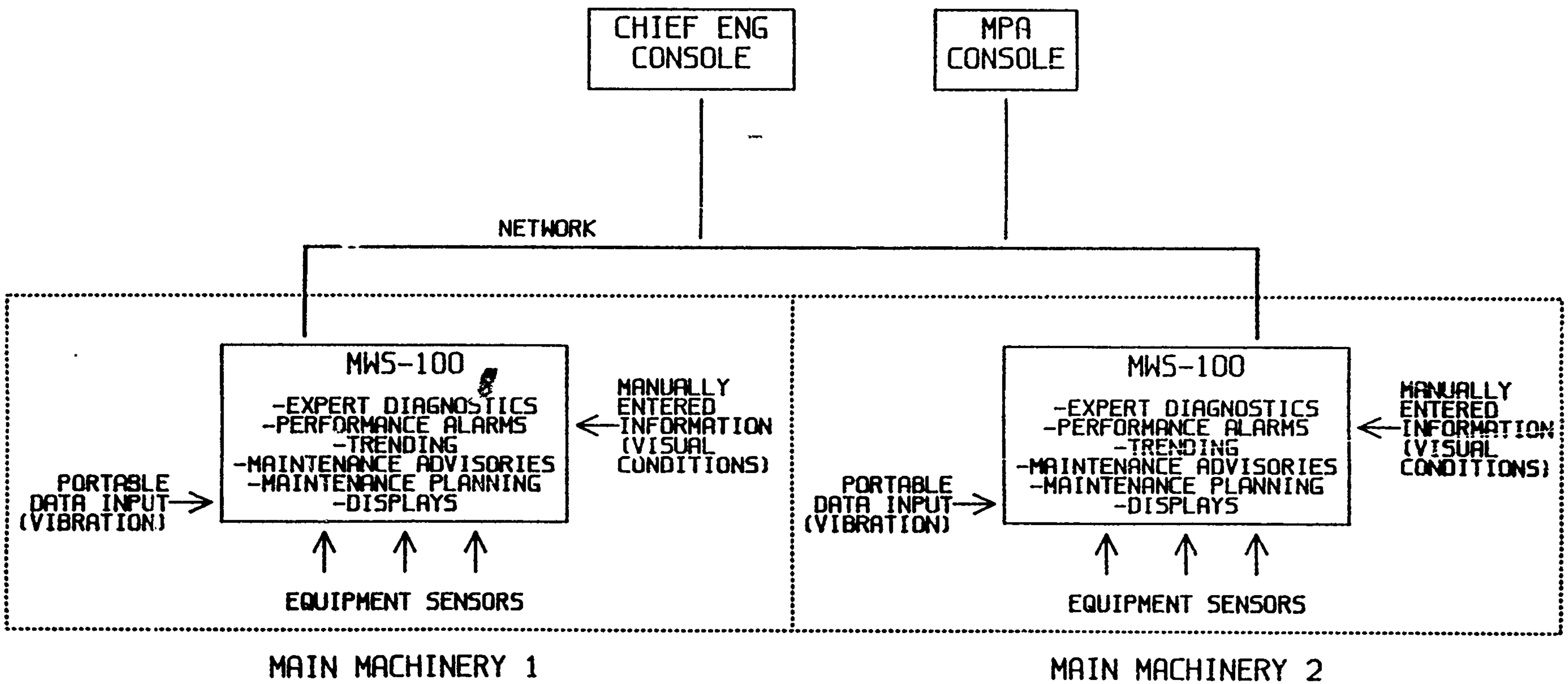


FIGURE (3)

TYPICAL PCAS DATA FLOW

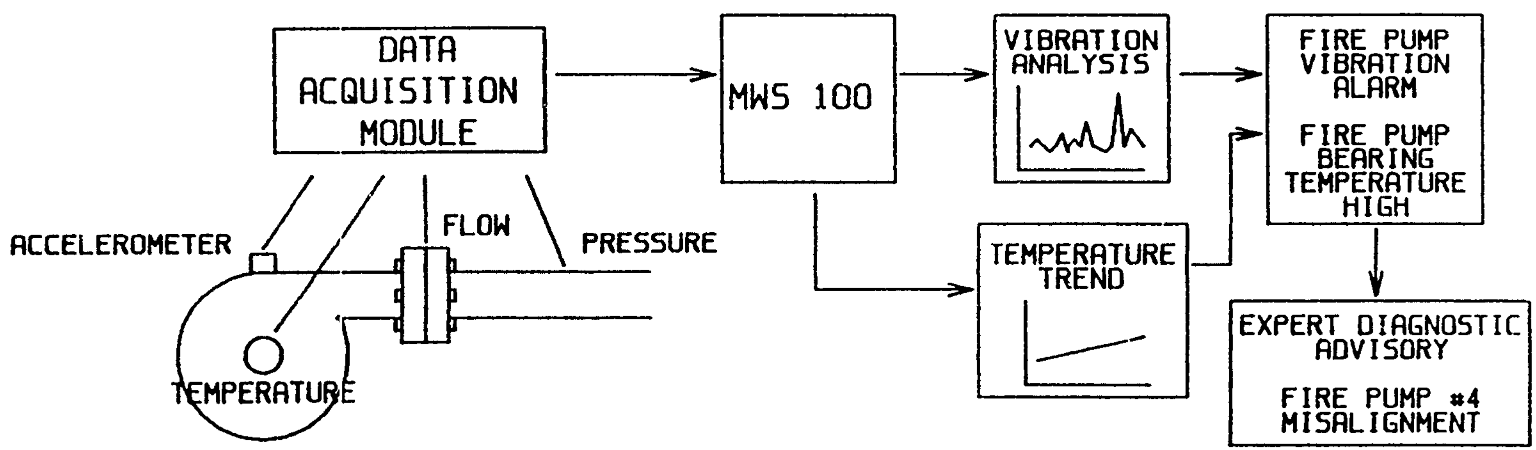


FIGURE (4)

TEST PROGRAM TASKS AND SCHEDULE

The major tasks in the Test Program are listed below with an estimate of the relative beginning and ending times.

Task Number	Task Description	Lead Assist	Week Begin	To End
1	Prepare instructional material, including outlines, presentations, charts, handouts.	SSMO ---	1	4
2	Instruct SCRF planning personnel in developing work package and applying decision logic.	SSMO SCRF	5	6
3	Modify logic, development procedures and instructional material.	SSMO ---	7	7
4	Update ship maintenance history data as required.	SCRF SSMO	2	12
5	Complete those portions of Work Determination Outline (see Appendix A) that are class-wide (joint SCRF-SSMO).	SSMO SCRF	7	12
6	Complete Work Planning Procedures and develop work package for one ship (joint SCRF-SSMO).	SSMO SCRF	13	18
7	Revise logic, procedures and instructions. Write draft handbook. Oevelop supporting computer programs.	SSMO ---	19	26
8	SCRF develop work packages for two shlps independently.	SCRF ---	19	30
9	Estimate Ao, repair costs, planning costs for control ships.	SSMO SCRF	19	30
10	SSMO review two work packages.	SSMO	31	31
11	Train in use of handbook and computer programs.	SSMO SCRF	32	32

TABLE (1)

12	SCRF develop work packages for two additional ships independently.	SCRF	33	44
13	Evaluate results of two ship availabilities.	SSMO ---	49	82
14	Answer other test questions.	SSMO	44	50

The content and purpose of many of the above tasks are self-evident. The following comments state the intent or amplify the substance of the remaining tasks.

Tasks 3 and 7. Modifying the decision logic and work determination procedures should be an almost continuous task based on insights of both SCRF and SSMO personnel. It will be particularly effective to update the documents as a result of experience in Tasks 1 - 2 and 4 - 6.

Task 4. To develop necessary estimates for control ships (see Task 9), data about past availabilities should be complete. This task will complete, to the extent possible, the 7 1/2 percent of task records that are incomplete. To make accurate assessments of jobs to be done, planners must have a complete maintenance history of the Ships for which availabilities are to be planned using the new logic and procedures. Task 4 will attempt to provide a complete maintenance history on the ships to be used in the test.

Task 5. Some of the steps in the Work Determination Outline (see Appendix A) relate generally to the class as a whole; others are primarily applicable to individual ships. Class-wide or nearly class-wide steps include I3, I4, IS, II, III and IV. Tasks 6, 8, and 12 complete the Work Planning Procedures for specif~c hulls.

Task 7. The SSMO will have enough experience at this point to begin preparation of a draft handbook of Work Planning Procedures and of supporting computer programs. The computer programs will assist in data recording, handling and retention and will perform much of the arithmetic required in risk assessment.

Task 9. The control Ships are those 5 ships completing availability just prior to 1 March 1989, when instructional development and training begin on the new Work Determination Procedures. Oata on these ship availabilities must be collected for comparison with statistics related to the two test ships for which work planning will be done in Task 12.

TABLE (1) contd.

Task 14. Answers to three of the four test questions should be available shortly after completion of work packages for the two test ships. Answers to the remaining question concerning the quantitative results of the new work packages in terms of Ship Ao will not be available until 6 months after repair work has been completed. This is the reason for the late ending data for Task 13.

table (1) contd.

STATUS SUMMARY OF MAINTENANCE NEEDS

MAINTENANCE NEED	STATUS
Dehumidification of Reduction Gears	NAVSEA has developed a solution.
Forced Draft Blowers and Main Feed Pumps	Adequate personnel training is probably the best solution to this problem.
Replacement for Butterfly Valves in Seawater Systems	This issue is being examined by NAVSEA.
Limitorqe Actuators	This issue has been addressed by NAVSEA.
Stellite Surface Valve Repair In-Place	Better problem definition required.
Intake Ductwork Material	NAVSEA is working to resolve this problem.
Paint Systems	These systems exist, however, NAVSEA approves their use on a case-by-case basis.
Deck Coverings	NAVSEA recommends use of ceramic tile.
Anchor Chain Preservation	No new developments identified.
Flame Spray Equipment	Equipment is continuously evolving.
Air Quality Sensing	Several potential commercial systems identified.
HESS Stations	Potential commercial solution identified.

TABLE (2)

STATUS SUMMARY OF NEW TECHNOLOGIES (CONT.)

TECHNOLOGY	Commercial Product/Process Available; Navy Development Program Underway	Commercial Product/Process Available; Navy Having Difficulty Implementing	Commercial Products/Process Available; No Navy Program Identified	Other	Cost/Benefit Score (+3 = Most Attractive; -3 = Least Attractive)	Risk Analysis Score (8 = Lowest Risk; 0 = Higher Risk)	COMMENTS
Laser Alignment			X		-1*	6	Possible benefit resulting from of ease of use.
Computerized Lathes			X		-3	5	Probably not practical for waterfront use.
Epoxy Coatings				X	2*	8	Extensive development work has been performed by NAVSEA.
Synthetic Lubricants				X	1	8	Synthetic lubricants are approved and available.
Spectacle Flange Type Valve				X	1	8	Spectacle flange type valves are used where possible by ship designers.
Diesel Engine Fuel Purifiers				X	1	7	Installations are performed on new construction.
New Insulations				X	0	8	Significant research is underway in both the Navy and industry to identify new materials.
Computerized Vibration Analysis				X	0	8	Currently implemented by SEMMSS program.
Electronic Circuit Board Repair				X	0	6	The Navy is currently performing circuit board repair, both in-house and contracted out.
Synthetic Sealants				X	0	6	Maintenance performed IAW manufacturer's specifications normally prohibits use.

TABLE (3)

STATUS SUMMARY OF NEW TECHNOLOGIES (CONT.)

TECHNOLOGY	Commercial Product/Process Available, Navy Development Program Underway	Commercial Product/Process Available, Navy Having Difficulty Implementing	Commercial Product/Process Available, No Navy Program Identified	Other	Cost/Benefit Score (+3 = Most Attractive, -3 = Least Attractive)	Risk Analysis Score (8 = Lowest Risk, 0 = Higher Risk)	COMMENTS
New Valve Operators		X			1	7	TLELFLEX valve operators are more expensive than rig rod & flex cable, but performance is superior.
Onboard Computerized Machinery History & PMS		X			1*	5	Shipboard systems not yet implemented by the Navy.
Borescope Equipment		X			0*	8	Equipment is available, increased training is required to achieve full advantage.
Non-intrusive Flowmeters		X			-1	8	Applications analysis required to identify additional uses for this technology.
In-place Machining (Valves) (Diesels)			X X		2 1	7 6	Although common in industry, NAVSEA generally opposes in-place machining for standrdization reasons.
Self-cleaning L. O. filters			X		1	8	Potential to eliminate filter changes.
Cryogenic Hardening			X		1	5	Requires an investigation of potential shipboard applications and performance.
Live Load Valve Stem Packing			X		1	4	Potential benefit for use on nuclear powered ships.
Protective Coating for insulation			X		0*	6	Potential benefit -- more information required.
Split-type Bearings			X		-1	7	Probably not practical for Navy applications.

APPENDIX A
WORK DETERMINATION OUTLINE

I. CLASS-WIDE REFERENCE MATERIAL

A. Collect background information

1. Alterative Maintenance:

Planned Alterations	=	the "shopping list" of the technical or military improvements which have already been identified (e.g., BOATALTs authorized for the class by PMS 300)
Scheduled Alterations	=	the list of alterations which will be installed, by availability, for which equipment repair will not be necessary

2. Ship configuration

Equipment
Components
Assemblies
Systems
System Interfaces
Reliability Block Diagrams
ESWBS Manual: *Expanded Ship Work Breakdown Structure for all Ships and Ship/Combat Systems*, NAVSEA S9040-AA-IDX-010/SWBS.
Other

3. Technical documentation about hardware

Construction Specifications
Plans, Blueprints, Drawings
Technical Manuals
Propulsion Operating Guide
PMS Documentation
Ship Information Book
Damage Control Book
Engineering Operational Sequencing System (EOSS), particularly Engineering Operating Procedures (EOP)
Changeout Program Requirements
Other

4. Equipment history

CSMP
Machinery History
Board of Inspection and Survey (INSURV) Reports
Inspection Reports

5. Policy Documentation

Mission Requirements (USNAINST 3120.1 series, OPNAVINST 3501.x series)
Overhaul requirements (OPNAVINST 4780.6 series)
Navy Ships Technical Manual (NSTM)
3-M Program
Other

B. Partition the ship

1. Define the ship by systems

   a. Identify systems' boundaries
   b. Identify systems' functions
   c. Identify systems' missions

2. Identify Functionally-Significant Items (FSIs)

All Systems
Selected Subsystems
Selected Equipments

C. Establish historical system/equipment failure information

1. Risk assessment information

   a. Compute each FSI's probability of failure with Failure Analysis System
   b. Determine each FSI's severity of failure

2. Build reference list for Pre-Availability Inspection (PAI)

   a. Determine what methods for determining material condition of hardware (historically dominant failure modes) exist, apply, and are in use

PMS where appropriate
Off-ship test or inspection where needed

b. Determine what failure prediction techniques exist, apply, and are in use

Age-Reliability Analysis
Vibration Trending
Navy Oil Analysis Program (NOAP)
Other

II. BUILD REPAIR WORK PACKAGE

A. Prepare Preliminary Work Package

1. Prepare for Pre-Availability Inspection (PAI)

a. Assemble inspection list

(1) Identify known failures

Current Ships Maintenance Project (CSMP)
Recent inspection results
Other sources

(2) Review Reference Package list of tests/inspections for applicable inspection tasks

(3) Ensure that tests/inspections do not search for known failures

(4) If known failures are not in CSMP, provide this information to ship's force

b. Schedule PAI for 13 weeks prior to start of ROH; coordinate with ship's force and squadron operations

2. Conduct PAI – provide ship's force with test/inspection results

3. Ship's force prepare Maintenance Action Forms (4790/2Ks)

4. Screen 2Ks

a. 3-M Coordinator screen for compliance with 3-M Manual

b. TYCOM screen for engineering and technical content

(1) Determine whether job is *applicable and effective* (RCM criteria)

Approve only jobs which are *applicable and effective*

(2) Determine appropriate kind of work and maintenance echelon (Repair Decision Logic, Appendix B)

Alteration or repair
O, I, or D-level

B. <u>Prepare Proposed Work Package</u>

1. Plan/Estimate (P&E) Preliminary Work Package

2. Assess risk of deferring jobs in P&E'd Work Package

a. Determine budgetary information

Labor manhours available
Material dollars available
Percentage to be held in reserve, for growth/new work

b. Risk of system failure: Risk Analysis System's *Risk Assessment Report*

Risk-sorted list of jobs in Proposed Work Package
Checkbook format: each job reduces amount remaining in budget

c. Risk of late work authorization

3. Assemble Proposed Work Package

SCRF *Ship Report* (CSMP)
Risk Assessment Report
Late Work Authorization Worksheet

C. <u>Generate Authorized Work Package: Work Definition Conference, 9 weeks prior to ROH</u>

1. Confirm each job's:

Validity
Workcenter assignments
Cost estimate

2. Identify any jobs which must be deferred due to lack of resources

   Initial identification from risk of system failure (*Risk Assessment Report*)
   Confirm by comparing risk of system failure with risk of late work authorization

3. Develop risk management plan: in case system fails, identify measures to control impact on

   Ship operations
   Depot operations

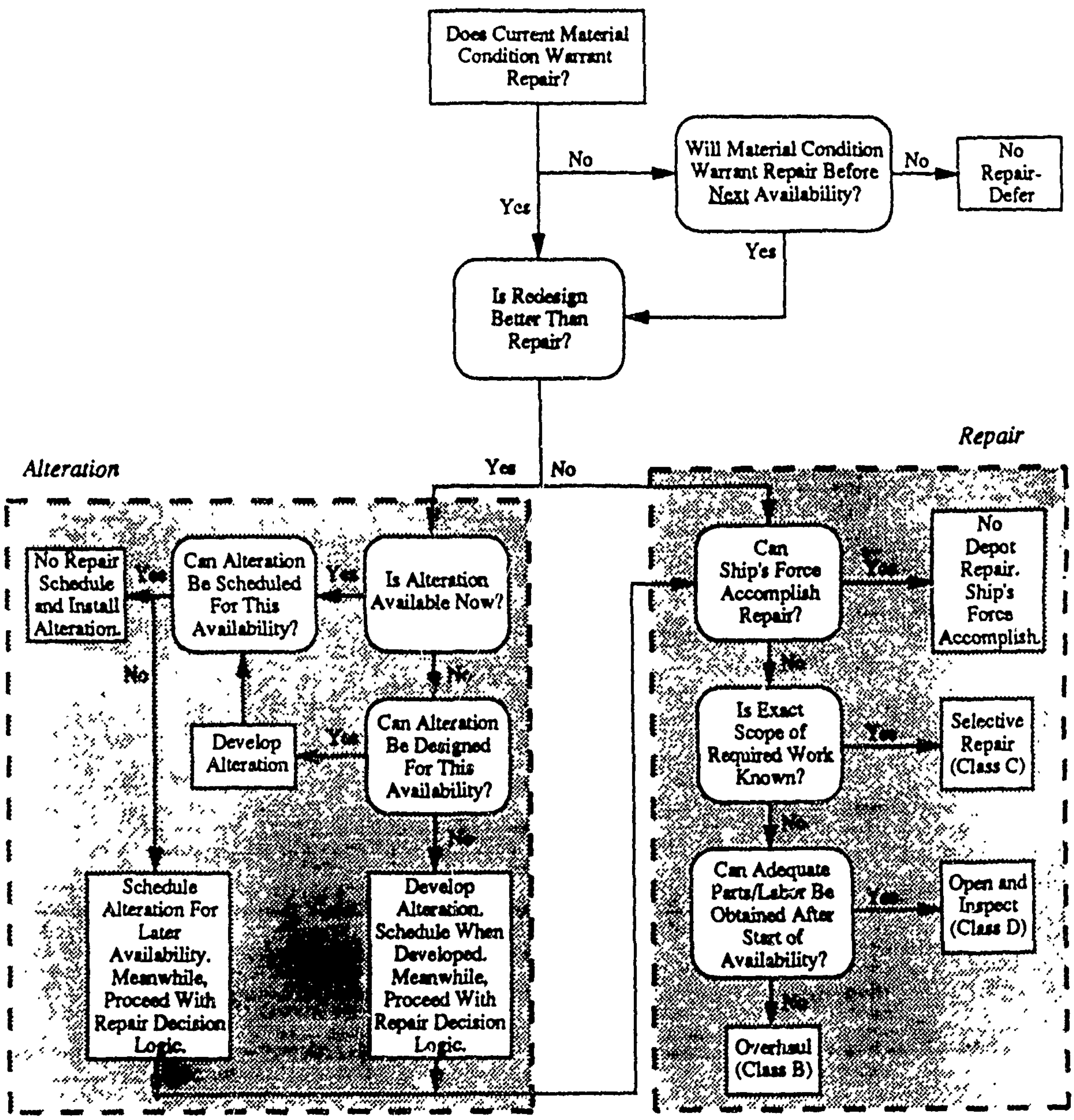
D. Provide Completion Work Package

1. Approximately 4 weeks after ROH completion, submit Completion Work Package

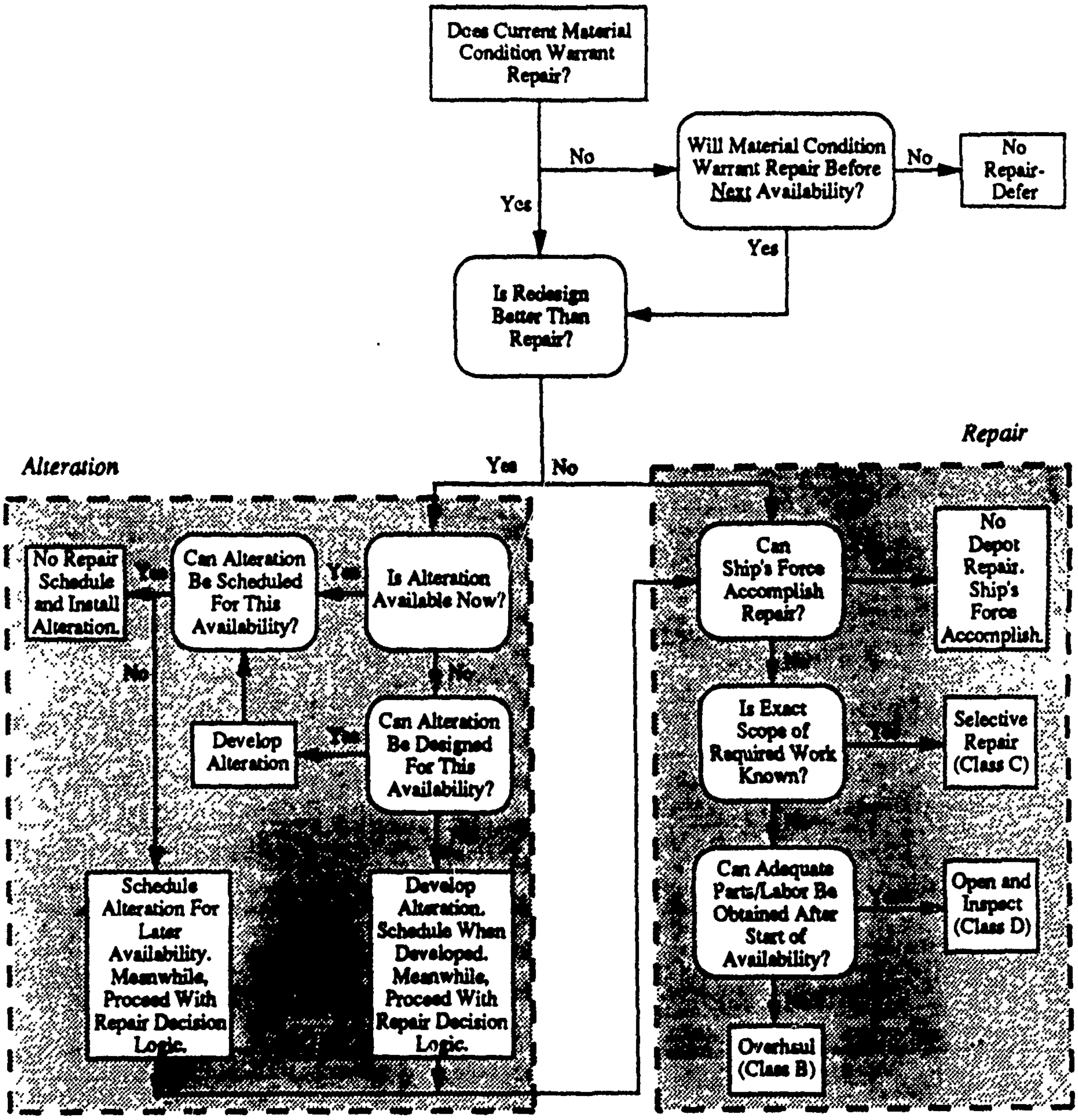
2. Update reference package to reflect work done during availability

   System configuration changes
   New failure/repair data for Failure Analysis System

APPENDIX B
REPAIR DECISION LOGIC



APPENDIX B
REPAIR DECISION LOGIC



APPENDIX C
EVALUATION PROCEDURES

The basic information being evaluated in this test is (1) the cost of YP repair work performed at the Small Craft Repair Facility (SCRF) at Naval Station Annapolis, and the operational availability (A_o) of the YPs supported there. The Test Program will be deemed a success if it is able to provide RCM-based repair planning tools without causing a significant increase in the SCRF's repair expenditures for its YPs, or a significant drop in the YPs' A_o.

C.1 MAINTENANCE COST DATA

The most complete source of SCRF cost data lies in a dBASE III+ database maintained by the SCRF's Records/Accounting Office. This database goes back to FY 86. The applicable elements in this database are:

Selection Criteria	**Numerical Values**
Vessel	Actual Hours (Total)
Date job request received by SCRF	Actual Materials Cost
Date job started	
Date job completed	
Date completed data entered into database	
Alpha Category	

The *selection criteria* fields are used to identify those records which contain pertinent cost information. The *vessel* field separates 676-class YPs from the other small craft supported by the SCRF. The *Alpha Category* field can do so as well, since it is currently used to assign unique codes to work centers.

The *date* fields separate YP-related work in term of the time periods being examined: the Control period, before the APIP was implemented; the Transition period; and the Test period itself. *Dates data received/completed* refer to the dates when the data were entered into the database. *Dates job started/completed* refer to the dates written on the 4790/2Ks and 4790/2Rs, reporting the start and stop dates of the work itself. Neither set of dates is completely accurate; however *Dates data received/completed* are probably least accurate, since they tend to cluster around the dates when the people who enter data accumulates enough forms to move them to enter them. The errors in *Dates job started/completed* are probably sufficiently random to permit them to be used in order to segregate the jobs into the relevant time periods.

The *numerical value* fields provide man-hour and material cost data. YP-676 repair cost data have been gathered for the period before the APIP. These data will be compared to YP-676 repair cost data for the test period.

The cost data in this database are not without flaws. This and other databases in the SCRF have been installed relatively recently, and during installation SCRF management was fully occupied with putting them in place. During the preliminary review of SCRF procedures before the APIP began, SCRF management indicated its intention to shift its attention to supervising the proper use of the databases. As a result of the management priorities during the period before this review, there are two sets of potential problems with the cost data in this database: accuracy, and completeness.

Problems with data accuracy will probably affect the figures for man-hours more than the figures for the costs of materials. Materials' costs can be entered relatively easily, from vouchers and receipts; but man-hours are susceptible to seat-of-the-pants "estimates". Because of this, SCRF Records Office personnel are skeptical about the validity of man-hour numbers associated with specific jobs.

One advantage of the approach being used here is that the goal is to identify *changes* in total spending. If cost data are entered during the test period in basically the same way they were entered during the control period, then we may assume that they would be subject to the same errors in both periods. We may then compare the cost data of the two periods to see if there has been a significant change.

Maintenance cost data also do not show some details we would like to examine. It would be very worthwhile to examine the man-hours of planning personnel, such as SUPSHIPS, TYCOM, and 3-M Coordinator, to see whether the APIP planning procedures place a significantly different burden upon them. Unfortunately, the SCRF's availability cost accounting only budgets, and records, *direct* labor: labor which contributes directly to specific repair jobs in an availability. *Indirect* labor – labor that cannot be charged directly to a specific repair job – is not covered. When a SCRF SHIPSUP spends his day doing advance planning for several vessels, his hours are not recorded against the individual vessels' availabilities. Therefore the only labor comparison available is a comparison of direct labor hours before and after the APIP procedures were implemented.

C.2 MAINTENANCE PERFORMANCE DATA

The measure of "effectiveness" laid down by OPNAV is Operational Availability (A_0). This is a *ship* performance measurement, not a *maintenance* performance measurement such as material condition. From the point of view of engineers determining the most appropriate and effective repairs for a piece of equipment, information about material condition is essential. However from the point of view of OPNAV evaluating the "bottom line" of those repairs, what is essential is the ability of the ship to perform its assigned missions.

The classic definition of A_0 is the following equation:

$$\frac{\textit{Time able to perform mission}}{\textit{Total time}}$$

Several specific definitions of *time able to perform mission* and *total time* are available. Some include shipyard time (C5 status) in *total time*; some include different kinds of equipment casualties as *time unable to perform mission.*

For the purposes of this test, *total time* consists of the time *not* in a scheduled SCRF availability (ROH/RAV), corresponding to the time a ship would *not* be in C5 status. For the purposes of this test, *time able to perform mission* consists of time that a YP is *not* in a scheduled SCRF availability, and also time that a YP is *not* declared unavailable for unrestricted operations. This corresponds to the time a ship would *not* be in C5, C4, or C3 status.

Most Navy ships use OPNAV's CASREP system for reporting equipment casualties. Calculations for their A_o depend upon their operational status as documented by their CASREPs. This mechanism is not available to this Test Program, because the SCRF does not report to OPNAV under the CASREP system. It reports casualties only locally, by other means: either in a Weekly Status Report to the NAVSTA Commanding Officer, or by notation in the Operations Department schedule describing the YP as "down". The Test Program accepts either documentation as evidence that a YP was not available to perform its mission.

The Weekly Status Report reports a YP as "down" if it is incapable of performing its primary mission. This corresponds to a C4 CASREP, required for a casualty which results in "loss in a primary mission area". If the YP is able to get underway for local training, but is not able to support longer cruises, the Weekly Status Report will report the YP as "up", but "restricted to local operations". For the purposes of this Test, this condition is deemed to correspond to CASREP condition C3: "degradation in a primary mission area". Either a C3-equivalent or a C4-equivalent problem counts against a YP's A_o.

It should be noted that not all YPs are declared "down" because of equipment problems. The YP Division is not manned to support operations by all YPs simultaneously, so a YP may be declared "down" under circumstances which a larger ship might declare a "Personnel CASREP". The Weekly Status Report usually describes the reason why a YP is declared "down", so it should be possible to weed out these reports.

TAMING THE TIGER
NAVSEA's RELIABILITY, MAINTAINABILITY, AND AVAILABILITY ANALYSIS PROGRAM

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ABSTRACT

The TIGER computer program is the major tool used by NAVSEA Code 05MR for performing Reliability, Maintainability and Availability analyses on Naval Ships and Associated Ship Systems. It is undergoing several major enhancements, one of which involves an interactive graphics user environment. The standardization of the X Window System along with the maturity and commercial acceptance of object-oriented programming has created the opportunity to dramatically improve the way TIGER reliability models are developed and used. The TIGER computer program in its current version performs Monte-Carlo type simulations for a system reliability block diagram. The block diagram itself is represented as a hierarchal numbering scheme readable by Fortran (programming language) format statements; friendly for the computer but not friendly for the user.

This paper is concerned with the user interface; making it not only more user-friendly but also more directed toward providing the user with a view that emphasizes the model rather than a view that is a compromise with computer processing. In dealing with this concern, the concepts associated with object-oriented programming will be introduced. The paper will elaborate on how the concepts affect the users perspective as well as the programmers perspective. The paper will also introduce the X Window System and elaborate on some of the features that are used in the TIGER graphical environment.

LIST OF FIGURES

TABLE OF NOTATIONS

CAD	Computer Aided Design
NAVSEA	Naval Sea Systems Command
RBD	Reliability Block Diagram

INTRODUCTION

The history of object-oriented programming had its beginnings with simulation. The TIGER computer program is a simulation program used by NAVSEA to analyze reliability, maintainability and availability of systems. By discovering the problems that object-oriented programming is addressing, information can be obtained on potential solutions to problems associated with TIGER modeling.

The focus of this paper is on concepts associated with object-oriented programming and their application to the TIGER computer program. Three key areas of object-oriented programming are discussed. First is the approach toward making the TIGER program input file more object-oriented. Second is the selection of a graphical environment known as the X Window System and the features that make it object-oriented. Third is the topic of object-oriented database systems, their philosophy and application to computer aided design.

The paper concludes with an example of integrating the object-oriented topics with TIGER. The example is intended to give the reader an idea of how all of the topics discussed could be applied.

PROBLEM SCOPE

** WHAT ARE THE PROBLEMS ? **

The problems associated with TIGER modeling are not unique to the TIGER computer program. The TIGER computer program falls under the category of computer aided design (CAD) and shares many of the same problems. Likewise, problems associated with large TIGER models are similar to problems associated with large software projects, and to a certain extent any large project. There are three basic problem areas associated with TIGER modeling. They are model construction and modification, model reusability, and model evolution. The fundamental parts of a TIGER model are the Fortran (programming language) input data file and a reliability block diagram (RBD). A sample TIGER input file can be seen in Figure 1 and its associated reliability block diagram is shown in Figure 2.

The basic entities in the TIGER input file are equipment, the configuration of equipment in systems and a scenario for the platform. Features of an equipment include basic reliability data (mean time between failures, mean time to repair, duty cycle), equipment number assignments, and sparing information. Equipment are configured in groups which define levels of redundancy. The systems take on various configurations as defined for the scenario. The scenario includes the type and duration for each configuration as expressed in a timeline.

The reliability block diagram and the input file are two representations for the same information; The input file is readable by the computer and the block diagram is readable by the TIGER modeler. Prior to the reliability block diagram, typically a functional block diagram is developed by a design engineer. These three representations are typical of CAD environments where there are often design hierarchies. This multilevel representation scheme is necessary but leads to problems.

One of the problem areas is user comprehension and understanding. Observing Figures 1 and 2, one will notice that group number 701 (in the System Configuration section) contains equipment numbers 1, 2 and 3. These equipment numbers correspond to equipment types 1, 2, and 3 which are the BRIDGE CONTROL, ELECTRIC CONTROL and LOCAL CONTROL. The first thing one may notice in this comparison is that it helps if the modeler has the block diagram in front of him when trying to read the input file. In fact it is very important for the diagram to be kept up to date with the data, especially for very large models. Also, this situation is increasingly complicated when modifications are made. For example, suppose the modeler needed to add a group to the model. This is trivial in the small sample model, however in large models it is a labor intensive task and has potential for messing up any organization the modeler might have been using.

As user comprehension and understandability decrease, the quality also is difficult to enforce. The time and effort to validate a model is long and tedious, especially when a large number of modifications are made. Also associated with comprehension and understandability is productivity. Since productivity is associated with time and accuracy, with large models and many modifications, productivity drops off.

Contributing to these problems is the fact that the input file format allows the user considerable freedom in terms of the model. For example, there is no specification for the names that can be used for an equipment type. Thus for this version of the model the modeler may use the name Bridge Control and in another version of the model use Bridge Control Console; possibly because the data source labeled it these two different ways. Similarly, other identifying elements such as group numbers, equipment numbers and equipment type numbers may vary between versions of the model. In essence, the file format leaves the organization and control aspects of modeling up to the modeler.

The problem that the identification flexibility leads to is a lack of reusability. A lot of information already available in other TIGER models cannot be directly reused. Existing model information is treated essentially the same as new model information. This is especially true with the configuration information in the input file. Inconsistencies in numbering between other models forces the modeler to re-iterate the information.

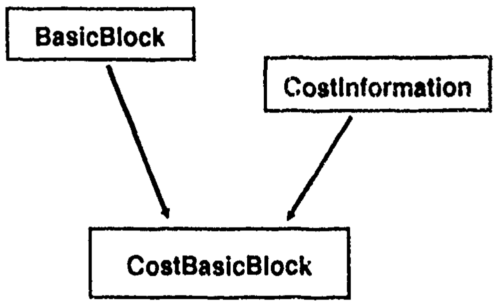
Even when experienced modelers plan for model expansion and modification, as the model evolves, changes that occur will usually effect the total model; a tendency that leads the model to be inconsistent with earlier versions of the model. Thus changes are difficult to track and compare.

POTENTIAL SOLUTION

Object-Oriented Programming: Brief History

A technology that is gaining in popularity in the world of computing is object-oriented programming. Object-oriented programming originated with the invention of

the modeler wanted to add the aspect of cost to the original class, this could be done by creating an object consisting of the basic object of the class BasicBlock and combining it with the aspect of cost. The new object would be of a new class possibly named CostBasicBlock. The class CostBasicBlock would inherit all characteristics of the original object in class BasicBlock plus it would inherit the characteristic of cost. This inheritance path would appear as follows:



EMERGENT TECHNOLOGY

Why the X Window System ?

First of all, if there is any chance at all to create a non-proprietary, yet portable graphical interface, the X Window System is it. One could develop one from scratch, but this would be re-inventing the wheel and would also be specific to the machine it was developed on. One could develop a PC based application, but this would be specific to a class of platforms and operating systems and would not even be practical for a program the size of TIGER.

Two key benefits are derived from the X Window System. They are vendor-independence and network-transparency, and standardization. This means that the X Window System can be used in a network environment in the same manner that it is used on a single workstation. An X Window application will run on a single high end graphics workstation, but alternatively can be distributed to run on several networked low end graphics workstations (such as 80286 based PC's) connected to one high end workstation. Networking low end workstations with a single high end workstation is more cost effective than having independent high end workstations when there are several users. The X Window System allows for sharing of the graphical interface as well as sharing of the application program.

Another consideration important to the Government is standardization. The X Window System library and protocol are being incorporated as part of the POSIX standard (Fips 151). This should help spread the acceptance and portability of X Window applications, ie., the basic requirement is that the user have direct or network access to a workstation running a POSIX compliant operating system.

All said, there is a downside to using the X Window System. First, it pushes the state of the art in computing environments. The traditional interface to programs running on a central corporate computer is by way of an ASCII terminal, connected at least by a modem. Modems are out of the picture for the X Window System; at least for a graphical interface. Also, terminal emulation software is expanded to include network driver software, an Ethernet card, special X Server software, and be connected via network. Second, it pushes hardware requirements. Staying within a 640 Kb of RAM is possible but not practical. Most PC X Server software is designed to take advantage of whatever RAM is available (vendors usually recommend a minimum of 4 Mb of RAM). EGA Video Monitors are the minimum recommended display device, however, at least a VGA Monitor is more practical.

Even with these considerations, the X Window System is the way to go if you want a graphical interface. The trend in POSIX compliant platforms is toward smaller machines and lower prices. While it is pushing the state of the art now, it will be just common environments in the near future at the rate computer technology is moving.

Basics of the X Window System

The X Window System is based on an object-oriented structure. The interface consists of self contained objects that when activated perform some function(s). The underlying system contains a Main Event-Reading Loop that watches for actions by the user such as mouse button events and keyboard input events. The X Window System is different from other single cpu window systems in that it is based on a network protocol.

User interface objects are known as Widgets. Some example Widgets are listed below,

WINDOW- graphical display object

PULL-DOWN MENU- command selection menu object

POP-UP MENU- optional command menu object

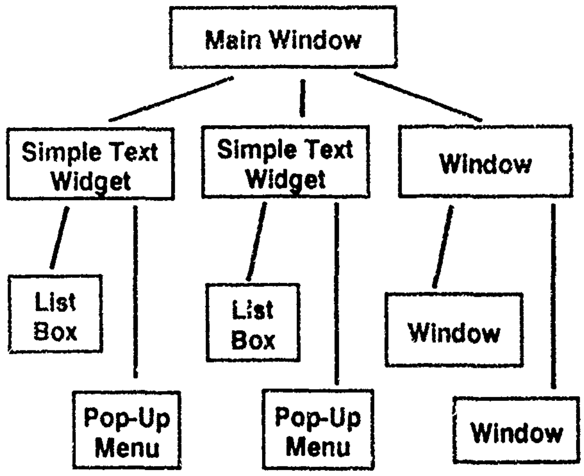
LIST BOX- view a list of elements

DIALOG BOX- a prompt for user input

Each user interface object belongs to a class. Libraries of Widget classes (referred to as the X Toolkit) are dis-

tributed with the X Window System software. Thus, the programmer can create Widgets that are instances of an existing Widget class, rather than developing an application from scratch.

In most cases a user interface object is a composite object consisting of several objects. The objects in a composite object are related in a parent-child hierarchy where the parent Widget has control over all of its child Widgets. A simple hierarchy is presented below:



This hierarchy describes the objects that make up the windows shown in Figure 5. The two simple text windows are at the top and the graphics window is at the bottom. Each simple text window is implemented with a list box that is used for scrolling through a list of elements and selecting from the list. Optionally, a pop-up menu (not shown in the figure) can be brought up on the screen for each simple text widget. The graphics window consists of two graphics windows. A main drawing window is above a smaller display window. The smaller display window is a container for icons.

Since the Main Window is the parent for all of the Widgets shown above, if it is moved, all of its children will move as well. Similarly, the simple text windows have control over their corresponding pop-up menus. The pop-up menus are brought to view while activity is within the corresponding simple text window.

When performing an activity such as clicking a mouse button or entering a key sequence,the user is effectively sending a message to a particular user interface object in order to have the object perform some function. Usually moving the cursor to within the boundaries of an object defines the object that the user wishes to communicate with. For example, consider the situation where the user wishes to make a selection from one of the pop-up windows. The procedure is first position the cursor inside a simple text window, then press the right mouse button. This sends a message to the simple text widget to bring to view the pop-up menu. Next position the cursor inside one of the entries on the menu, then press the left mouse button. This sends a message to the selected item (which is also an object) to perform the function associated with the object.

In summary, the X Window System is an object-oriented system consisting of simple user interface objects, composite user interface objects, a facility for sending messages to the objects, and functions that are associated with the objects.

FUTURE TECHNOLOGY

Modeling Control

As was mentioned earlier, the world of computer aided design shares a common set of problems. They include design alternatives and version control, and a standard library interface. Some of the problems sighted for the current interface to the TIGER program are due to a lack of control over such characteristics. Current research in object-oriented programming that is addressing these issues is the development of object-oriented database systems.

A quote that best summarizes the philosophy behind object-oriented database systems is "There is abundant psychological evidence that people use a large, well-coordinated body of knowledge from previous experiences to interpret new situations in their everyday cognitive activity" (Bartlett, 1932). To put this into perspective, consider when one observes data about the failure rate of an equipment. One would use any past experiences with this equipment to validate, or make sense out of the observation. If the observation results in a failure rate that drastically deviates from the previous experience, their is a natural tendency for one to question or even doubt the results. One might even be lead to analyze the differences.

Along the same line, newly developed equipment tend to be modifications to existing equipment as opposed to being completely new entities. For example, when developing a new steering system, the design for the most part is performed by making improvements/modifications to past designs, as opposed to starting from scratch (re-inventing the wheel, so to speak). Then when determining the failure rate of the new design, one would start with the failure rate of the older design and qualitatively and/or quantitatively assess the effect of the changes. The goal is to determine the impact of the changes and determine if they improve or degrade the design and why.

the computer language Simula back in the 1960's. Simula was developed as a language that addressed some of the problems associated with numerical simulations; More specifically, it addressed the problems associated with programmer control over the behavior of the simulation model.

In Simula, the data declaration and the procedures associated with those data were organized around the objects being simulated. Sets of objects that shared similar behavior were organized as a class. This gave a perspective that allowed the programmer to describe characteristics and behavior of objects. Because simulations often contained objects that were very similar to each other, an inheritance mechanism was incorporated into Simula. For example, consider a class that represents all the customers that enter the post office. This class defines the behavior that is common to all customers. Thus each customer will perform some set of tasks. In addition, however, different customers may perform some particular tasks. CUSTOMER1 may have to send a registered letter, pay rent on a box, and apply for a passport, whereas CUSTOMER2 just wants to buy a role of stamps.

Control over the behavior of an object was enabled by a mechanism known as message passing. A message is a statement that tells a particular object to perform a particular action. Thus the programmer controls the behavior of the model by sending messages to the objects. For example, a message "ACTIVATE CLERK" will cause a clerk to begin performing its tasks. This style of defining behavior for objects and controlling their behavior has come to be known as object-oriented programming.

The Xerox Learning Research Group developed a language known as Smalltalk that adopted and generalized the concepts introduced by Simula. In particular, it introduced the concept of superclass and subclass. Subclasses could add or even override characteristics and behavior of their superclasses. Also, Smalltalk provided classes that implemented user interface objects such as windows, command menus, object browsers and inspectors, etc. The developers of Smalltalk found simulation, as implemented by Simula, a useful framework for their research in user interfaces.

The Smalltalk approach of a windows type user interface has edged its way into just about all computing environments. For example the Apple Macintosh is designed around this technology, as well as Microsoft Corporations MS Windows and Presentation Manager. More recently, network based windows environments have begun to emerge. For example, the X Window System developed at MIT and Sun Micro Systems Network Extensible Windows System (NEWS). The X Window System was implemented with only a small hardware dependent kernel and network dependent kernel and is available for a minimal cost from MIT. The idea is that the X Window System will be adopted to many machine environments and many network environments; An essential property for use as a general network system, where there are heterogeneous systems all interconnected.

Today object-oriented programming takes on many forms. The following examples represent the various applications for which object-orientation can be considered, each providing increasing levels of control and flexibility to the programmer,

- Requirements Analysis
- Software Design
- Program Structure
- Software Environment
- Software Environment for Parallel/Distributed Computer Architectures

Additionally, there are specific object-oriented application areas emerging. They include Operating Systems, Database Management Systems and Computer Architectures.

Because the TIGER computer program is a simulation program, it was conceivable that object-oriented programming could provide solutions to some of the problems mentioned earlier. In particular, the approach to model development and modification could be improved by applying the technique of object-oriented program structure to the data in the TIGER input file. A graphical view of the model could be implemented by integrating the block diagram development process with a windows graphical user interface. Possibly, in the future, an object-oriented database could be implemented, and the degree of object-orientation of the entire computer program could be increased (extend the scope to procedures as well as data).

Object-Oriented Programming: Basic Concepts

Common to all object-oriented environments are the concepts of specialization, abstraction and information hiding. To a certain extent, these concepts are already practiced in TIGER modeling. First of all, consider the concept of specialization. Specialization in object-oriented programming means starting with the definition of the characteristics for a general class of objects

and defining more specific characteristics for related classes of objects. For example, refer to the block diagram shown in Figure 2. The modeler usually first develops a diagram for a general system (the diagram as shown), then using this basic system model, develops the diagrams corresponding to characteristics specific to different modes of operation for the system (illustrated in the table at the bottom of the figure).

Abstraction in object-oriented programming means arranging information in a hierarchy of least detail to most detail. By dealing with lower levels of detail, the user is concerned with a narrow scope of information. For example, refer to Figure 1. Group definitions are arranged in a hierarchy. Group number 706 is defined to contain group numbers 701, 704 and 705 (in the System Configuration section). By having the group contain other groups instead of equipment, the modeler abstracts out the details of the underlying configuration.

Information hiding is a technique used in programming in general as a means of allowing others access to only the information that is necessary for them to see, thereby disallowing them access to information that they do not need to see. On the other hand, by hiding unnecessary information, the user doesn't have to be concerned with certain hidden information. Information hiding is not currently practiced in TIGER modeling. An example application would be to eliminate group numbers from the graphical block diagram interface. By having group numbers hidden from the user, the system being modeled will appear in a consistent fashion even with modifications. For example, referring to the diagram in Figure 2, the Control Group will still be the same control group to the user even if its group number has changed.

According to the definition of object, the entire TIGER computer program can be considered an object; It consists of a set of data elements and associated functions. Thus the goal of using object-oriented program structure for the data elements in the input file translates to breaking up the file elements into object classes. In a traditional object-oriented sense, the goal implies giving control where it is most natural to the modeling process and take away control where it is unnecessary to the modeler but necessary to the computer.

Object in the real world are often viewed from a particular aspect(s). Equipment in TIGER, for instance, are considered from their fundamental reliability and maintainability characteristics when analyzing the reliability for the system. When extending the analysis to operational availability, the aspects pertaining to logistics and sparing are also considered for the equipment. Similarly, when extending the analysis to assessing manning, the aspects pertaining to manning must be added. For user flexibility, it is useful then to break out the aspects of an object.

Taking the concept of aspect to the total model, instead of one modeler and one model, there could be several modelers, where each person is responsible for a particular aspect(s) of a model. These persons could be from distinct parts of a project organization. For example, a team of modelers could consist of the equipment manager(s), the logistic manager, the configuration manager and the platform manager. The equipment manager would be responsible for basic reliability characteristics of the equipment. The logistic manager would be responsible for the sparing and logistics aspects of the equipment from the perspective of the platform that it is part of. The configuration manager would be responsible for alternative configurations for the platform comprising the equipment. The platform manager would be responsible for running alternative simulations.

Object-oriented programming accommodates aspects of an object through a facility known as multiple-inheritance (termed multiple-inheritance because it inherits characteristics from two classes). This is a fancy term that often leads one to the perception that it implies increased complexity. On the contrary, it is quite useful. To help in understanding this, recall the term specialization. In one respect it implies developing objects by defining more specific characteristics of existing objects. In another respect it implies developing objects in an incremental fashion, ie., preserving information in existing objects and incorporating only changed characteristics. In this light, one can specialize on an object by adding other aspects. For example, consider the reliability block class shown in Figure 3. The class BasicBlock contains the most basic data elements for a reliability block (a nomenclature, mean time between failure, mean time to repair, etc.). These basic elements are sufficient for the modeler to perform a simulation. Going down one level, this BasicBlock could be specialized by defining it as an item of a specific equipment. This block could be further specialized to include sparing characteristics, as depicted by the class SparesInventoryBlock. To do this, a modeler takes an existing block and adds the aspect of spares. In all cases, the information in the existing block is preserved, and the modeler only has to be concerned with one aspect at a time.

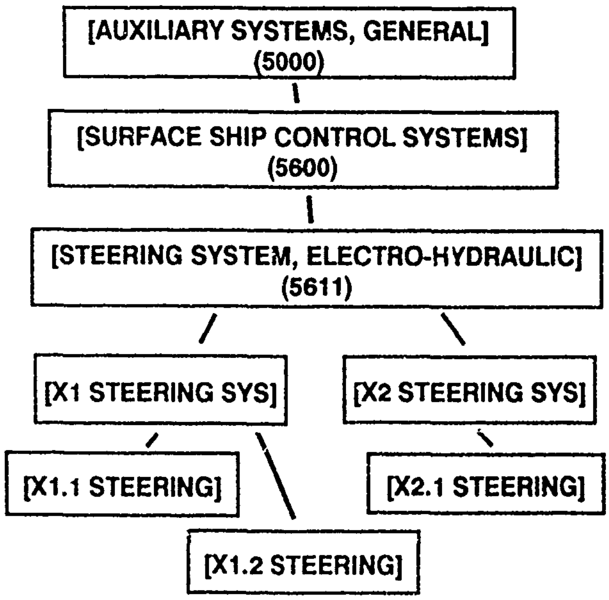
An additional benefit of multiple-inheritance is extensibility. First of all, because the original aspect of the object is preserved, once validated it doesn't have to be reconsidered. Second, any number of aspects can be added to the original object in a mutually exclusive manner. Thus adding aspects does not corrupt the original object but can extend the original object. For example, if

An Artificial Intelligence knowledge-representation technique that attempts to model these types of situations is called FRAMES. Frames provide a structure, or a framework, within which new data are interpreted in terms of concepts acquired through previous experience. The organization of this knowledge facilitates the capability to look for things that are expected based on the context one thinks one is in.

An example of a structure for a Frame can be viewed as follows:

FRAME
    Name:
    Type:
    IS-A:
    Properties:

The Name: refers to a unique name for the entity. The Type: can be either Class, Prototype, or Instance. A type Class refers to a category of objects (or functional group) and generic properties common to all or most of the objects in the class. For example, it might be determined that all steering systems have control components and hydraulic components. The type Prototype refers to a sub-category of objects and specific properties common to that prototype. For example, a prototype might be the first version of a type of steering system. An instance: type refers to a specific object. The IS-A: defines the hierarchical arrangement of the Frames in a class. It also defines an inheritance link where properties can be inherited from parent objects higher up in the hierarchy. Properties are sets of Attributes, Relationships and their Values. For example, a property might be Components = Bridge Control, Electric Control, etc. To illustrate the overall structure, consider a representation for steering systems:



The top three elements toward the top of the hierarchy are Functional Classes. They can provide default properties that are inherited by all specific elements lower in the hierarchy. These default properties can be overwritten by the more specific elements. The level below the last functional class are Prototypes. Values of properties in prototypes are typical default values for that type of equipment. Prototypes represent the basis for which specific instances can be developed or compared. Below the prototype level are the Instances. For the most part, these instances are almost identical to the prototypes with only minor differences.

The basic frame structure gives the essential features of an object-oriented database system. First, the structure facilitates the search for sets of instances that resemble but do not exactly match each other. Frames higher up in the hierarchy are more general than Frames lower in the hierarchy. Thus, a database system for retrieving Frames will locate the most specific Frame(s) that contains no conflicting properties as those specified. Second, it provides a natural organization for objects represented by a set of views. For example, a particular steering system may have different characteristics for each of its operating modes. Also, there may be a sparing model in addition to the basic reliability model. Third, it provides a facility to organize structures by function. The overall model can be laid out to parallel the hierarchy. The original model could consist of functional requirements, allowing the designer to explore configurations using different structures that can perform the function. Alternatively, as more detail is understood about the design, the overall model can be extended to include the more specific structures. Fourth, it provides the capability of maintaining a standard library. Using the frame structure lays out a strategy for a formal object classification and organization. Finally, the frame structure forms the basic support for design alternatives and version control. Overall models can be classified by the alternatives considered and by the improvements or modifications made.

APPLICATION

Putting It All Together

The resulting system is an interface system that gives the modeler a view that intuitively reflects the concept of the objects and relations that comprise the system being modeled. This is accomplished by a close correspondence between the graphical depiction of objects on the screen and the underlying computer representation of those objects. Two basic tasks can be considered fundamental to the interface system. They are Library development and maintenance, and Model development and maintenance. The task of Library development and

maintenance involves creating instances of Atomic Components and Composite Components and applying additional aspects such as sparing and shop information. The task of Model development and maintenance involves using libraries of components to develop models and performing simulations with those models.

Consider the task of creating instances of a Composite Component. A Composite Component, like a composite widget in the X Window System, is a container for Atomic Components and other Composite Components (this corresponds to a Group Definition in TIGER). This task can be performed using a browser window system like the one shown in Figure 4. The title is shown at the top of the main window - COMPOSITE COMPONENT EDITOR. Below this is a message line showing the current Library File and the modeling aspect that the file contains. At the heart of the editor window are three subwindows. The subwindow shown in the upper left contains a list of Atomic Components currently in the database; This list can be scrolled using the scrollbar associated with this window. The subwindow shown at the upper right contains a list of Composite Components instances that are located in the Library File; this list can also be scrolled. The larger window below these list windows is a graphics area where the diagram is displayed. The strip at the bottom is a container for icons. The icons in the Component Icon Box represent the class for Atomic Components and the class for Composite Components, respectively. The icons in the Relation Icon Box represent the class for Series Relationship, Active Redundancy Relationship, Passive Redundancy Relationship, and String Relationship, respectively.

Components are represented by blocks and circles, and relationships between them are represented by lines. The overall editing task consists of the following activities:

- The user selects an object from the Component Icon Box and moves it into the graphics display window.
- The system creates an instance of the object class.
- The user provides data associated with the object by selecting an item from one of the list windows, or by explicitly entering the data.
- The system asserts the data to the object.
- The user repeats the above steps for other objects.
- For each object, the user can define its relationship with two other objects; The user selects a relation object from the Relation Icon Box and asserts it between two objects in the graphics display window.
- The system automatically asserts relationship values to each adjoining object; If an objects relationship is asserted as a redundancy relationship with an object of the same type, the redundant object is depicted as a line on the screen; Objects located at the end of a set of objects will have a value of nil for one of its relation slots.

As an example of performing such a task, consider Figures 4 and 5. A sequence of events would be as follows:

- The user selects the block icon from the Component Icon Box and moves it into the graphics display window. The user then Selects the set of control Atomic Component(s) from the Atomic Component Browser Window and using the Pop-Up Menu associated with this window, Selects "Create Instances".
- The system creates instance(s) of the Atomic Components and displays them in the graphics display window as blocks.
- The user can provide particular overriding data associated with the atomic objects (if the user wants to override a database value); The user first selects an instance (clicks the mouse with the pointer over a particular block); A form pops up where the user can enter or modify information associated with the block.
- The system asserts the data to the object(s).
- The user Selects the Active Redundancy relation from the Relation Icon Box and asserts it between the Bridge Control and Electric Control blocks in the graphics display window. A redundant relationship is displayed between the blocks and they are positioned vertically.
- The system automatically asserts relationship values to each adjoining object; Figure 5. shows that the redundant slot for Bridge Control contains a value Electric Control, and the redundant slot for Electric Control contains a value Bridge Control.
- At any point in the model development, a set of Atomic Components and their relations can be combined into a Composite Object. This is done by first selecting the Composite Component class icon from the Component Icon Box and moving it to the graphics display window; The system creates an in-

stance of the class for Composite Components. Then with the pointer in the Composite Components Window, the user can bring up a Pop-Up Menu and Select "Create Composite Component". In the graphics display window, the user clicks on each Atomic Component (or Composite Component) to be included in the Composite Object. The user then selects "Save Composite Object" from the Pop-Up Menu. The set of selected components will then be replaced by the circle representing the Composite Component, and the Name of the Composite Object will be added to the Composite Components window. Each Composite Component displayed in the graphics display window has an associated Pop-Up Menu that allows the user alternate between displaying the next lower level of the Composite Component and the circle representation of the Composite Component.

Like Atomic Components, Composite Components can have relationships with two Atomic or Composite Components. As shown at the bottom of Figure 5., the appropriate slots are given values as relationships are established. In the figure, the Steering Control Group is in series with the Steering Pump Group.

Other aspects can be added to the basic aspect of the components to create sublibraries of the model. For example, the sparing aspect can be added to the components. This is done by asserting values for spares to individual or sets of Atomic Components, or by asserting overriding values to Composite Components. A color coding scheme is used to indicate the aspect that the component takes on. Components that have been given a spares aspect are separate objects from the original basic component, and are saved in a separate file whose aspect is spares.

CONCLUSION

Object-oriented programming takes on many flavors and can address a wide variety of problems. After performing research on the topic, it easy to see why it is gaining commercial acceptance. In terms of the TIGER computer program, applying specific object-oriented concepts has helped move the interface from being computer friendly toward being more user friendly. The interface is more toward a modelers intuition.

The problems addressed in the TIGER modeling world are also found in computer aided design and software engineering projects. Anyone in these arenas would be advised to learn more about object-oriented programming.

REFERENCES

[1] Barr, A., Cohen, P.R., Feigenbaum, E.A., The Handbook of Artificial Intelligence (1989), Addison-Wesley.

[2] Booch, G., "Object-Oriented Development", IEEE Transactions on Software Engineering, February 1986, Vol SE-12(2), pp 211-221.

[3] Bulman, D.M., "An Object-Based Development Model", Computer Language, August 1989, Vol 6(9), pp 49-59.

[4] Charniak, E., Riesbeck, C.K., McDermott, D.V., Meehan, J.R., Artificial Intelligence Programming Second Edition, (1987), Lawrence Erlbaum Associates.

[5] Fikes, R., Kehler, T., "The Role of Frame-based Representation in Reasoning", Communications of the ACM, September 1985, Vol. 28(9), pp 904-920.

[6] Foo, S.Y., Takefuji, "Databases and Cell-Selection Algorithms for VLSI Cell Libraries", Computer, February 1990, Vol 23(2), pp 18-30.

[7] Goldstein, D.G., "Object-Oriented Programming", DEC Professional, February 1990, Vol 9(2), pp 46-54.

[8] Goodwin, "Functionality and Usability", Communications of the ACM, March 1987, Vol 36(3), pp 229-233.

[9] Hewitt, C., "The Challenge of Open Systems", Byte, April 1985, Vol 10(4), pp 223-242.

[10] Hewitt, C., "Viewing Control Structures as Patterns of Passing Messages", Journal of Artificial Intelligence, June 1972, Vol 8(3), pp 323-364.

[11] Jones, O., Introduction to the X Window System (1989), Prentice-Hall, Inc.

[12] Keene et. al, Object Oriented Programming in Common Lisp (1988), Addison-Wesley.

[13] Kim,W., Lochovsky, F.H., Object-Oriented Concepts, Databases, and Applications (1989), Addison-Wesley.

[14] Pascoe, Geoffrey, "Elements of Object-Oriented Programming", Byte, August 1986, pp 139-144.

[15] Pinson, L., Wiener, R., An Introduction to Object-Oriented Programming in C++ (1988), Addison-Wesley.

[16] Pountain, D., "The X Window System", Byte, January 1989, Vol 14(1), pp 353-360.

[17] Stelzner, M., Dynis, J., Cummins, F., "The SimKit System: Knowledge-Based Simulation and Modeling Tools in KEE", IntelliCorp Technical Article, 1987, IntelliCorp, Inc.

[18] Stroustrup, Bjarne, "A Better C ?", Byte, August 1988, pp 215-216D.

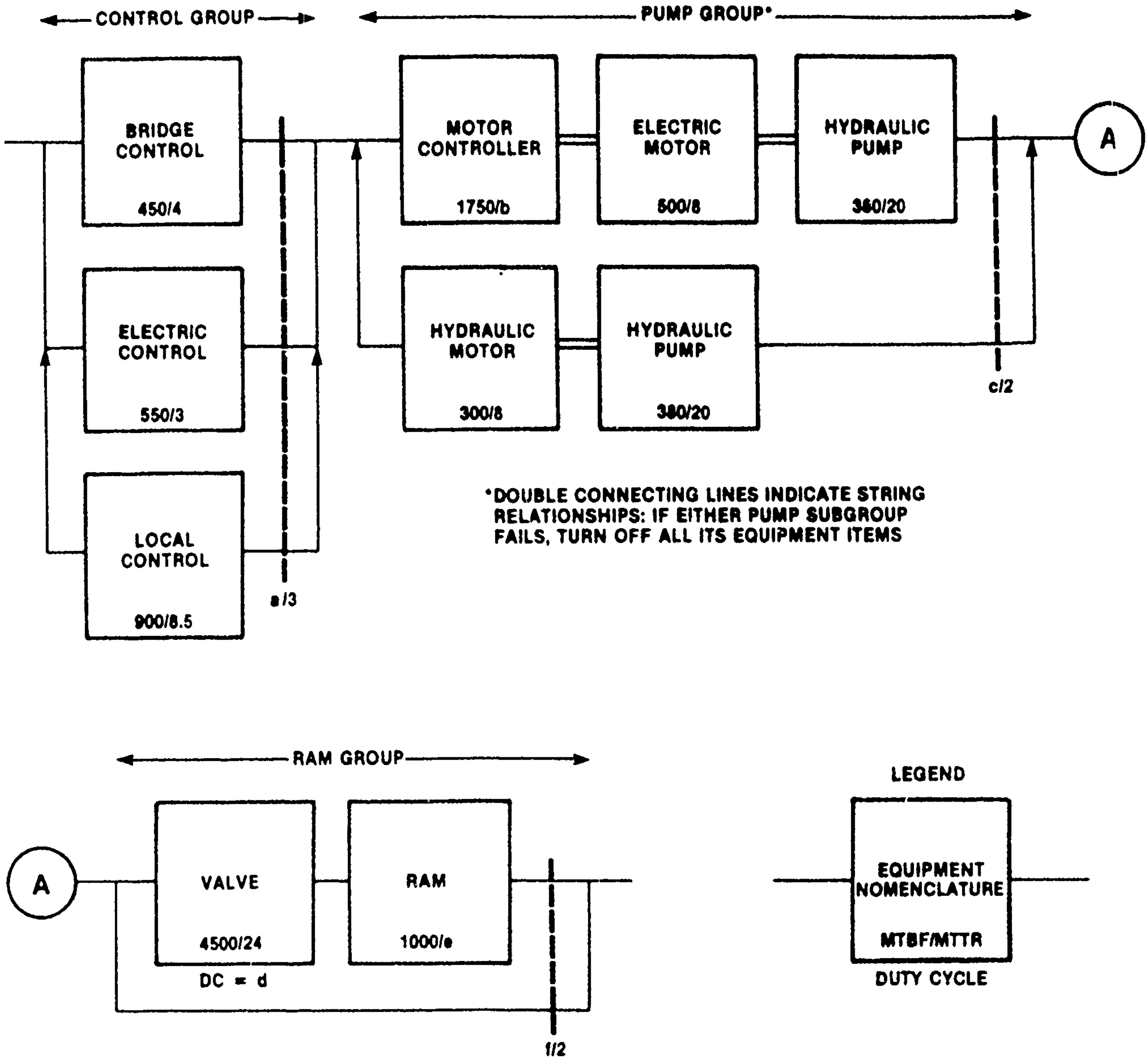
[19] Swick, R., Weissman, T., X Toolkit Athena Widgets - C language Interface, X Window System X version 11 Release 3, MIT Software Distribution Center, MIT E32-300, 77 Massachusetts Ave., Cambridge, MA 02139.

[20] TIGER Users Manual v8.21, NAVSEA TE660-AA-MMD-010, September 1987.

FIGURE 1. SAMPLE INPUT FILE: ENHANCED STEERING SYSTEM

```
    SAMPLE PROBLEM:  ENHANCED STEERING SYSTEM
 250         1.28       3

"TIMELINE"
 1 16.      2 9.      1 8.      2 17.     3 72.
 1 100.     2 10.     1 80.     3 72.

   4
   0   1   0

"EQUIPMENT DATA"     "MTBF" "MTTR"
   1BRIDGE CONTROL   450.    4.     48.          1.
   2ELECTRIC CONTROL 550.    3.     48.          1.
   3LOCAL CONTROL    900.    8.5    48.          1.
   4MOTOR CONTROL    1750.  -5.     96.          3.  1.0 0.9 0.8
 5. 9999 4.
   |
   9RAM              1000.  -10.    96.
"ASSIGNED EQUIPMENT NUMBERS"
   1   1
   2   2
   3   3
   4   4
   |
  10  12
"ASSIGNED EQUIPMENT SPARES"
EXCEPTION SPARES
   5 999 999   1
   4 999 999   2
   1 999 999   3
   2 999 999   4
               |
   1 999 999   8

"SYSTEM CONFIGURATION: 1st Phase Type"
CRUS    1   2 707
PUMP GROUP    704 10.
STRG CONTROL 701 10.
   1 701   1   2   3        "GROUP 701 DEFINITION"
   3   1   2                                1
   3 702   4   5   7
 702   4   5   7                            2
   2 703   6   8
 703 702                                    1
   6   8                                    2
   8   6                                    2
   1 704 702 703
   1 705  10  11
   4 706 701 704   9 705    "GROUP 706 DEFINITION"
   1 707 706
```

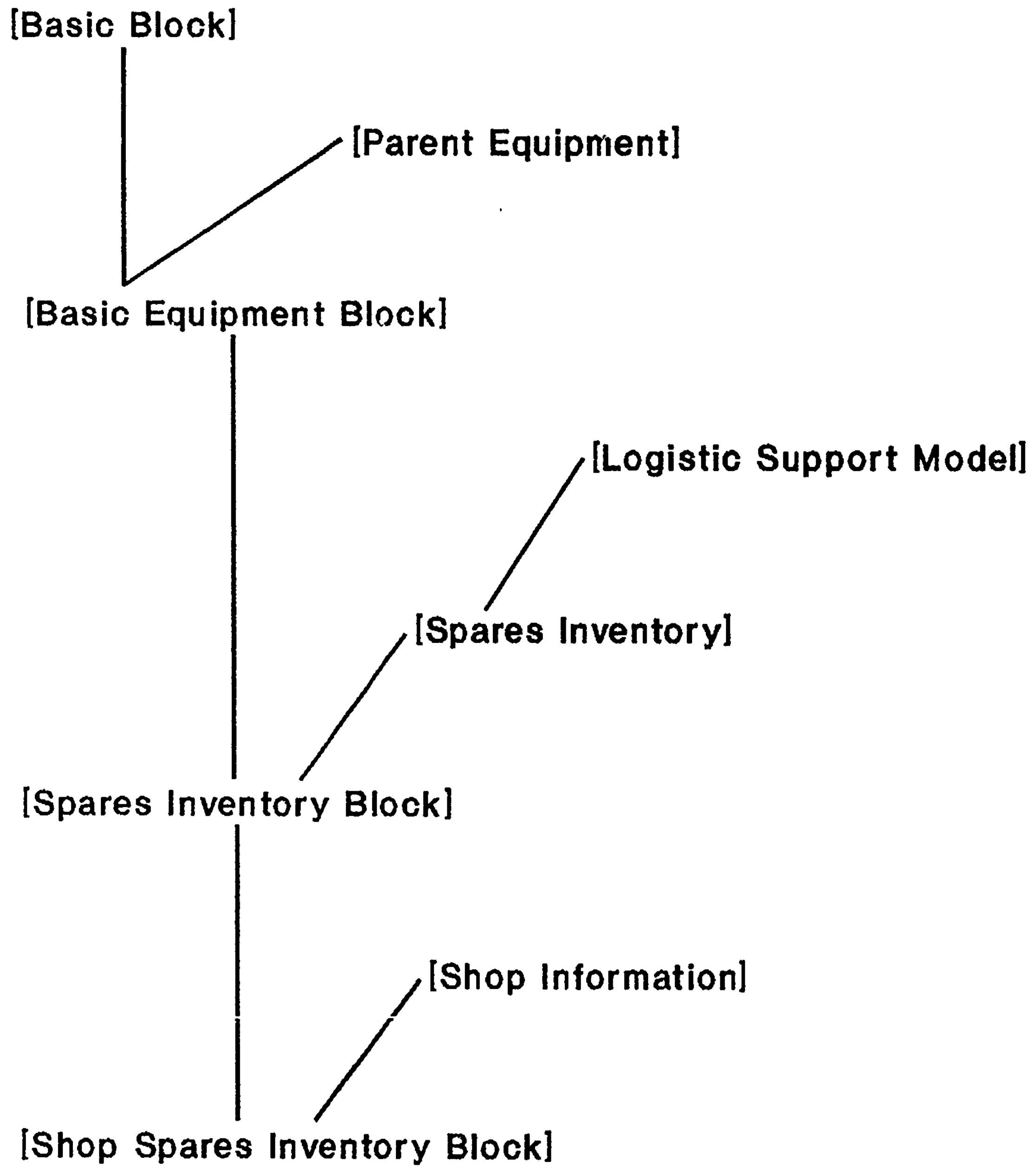
FIGURE 2. **SAMPLE RELIABILITY DIAGRAM: STEERING SYSTEM**



EQUIPMENT CHARACTERISTICS AND GROUP REQUIREMENTS TABLE

EQUIPMENT	PARAMETER	CRUISE	OPERATE	UPKEEP
a. CONTROL GROUP	NO. REQD	1	2	0
b. MOTOR CONTROLLER	MTTR	5.0	NR	4.0
c. PUMP GROUP	NO. REQD	1	2	0
d. VALVE	DUTY CYCLE	0.2	1.0	0
e. RAM	MTTR	NR	NR	10.0
f. RAM GROUP	NO. REQD	1	2	0

FIGURE 3. ASPECTS OF AN OBJECT;
INHERITANCE HIERARCHY FOR RELIABILITY BLOCK



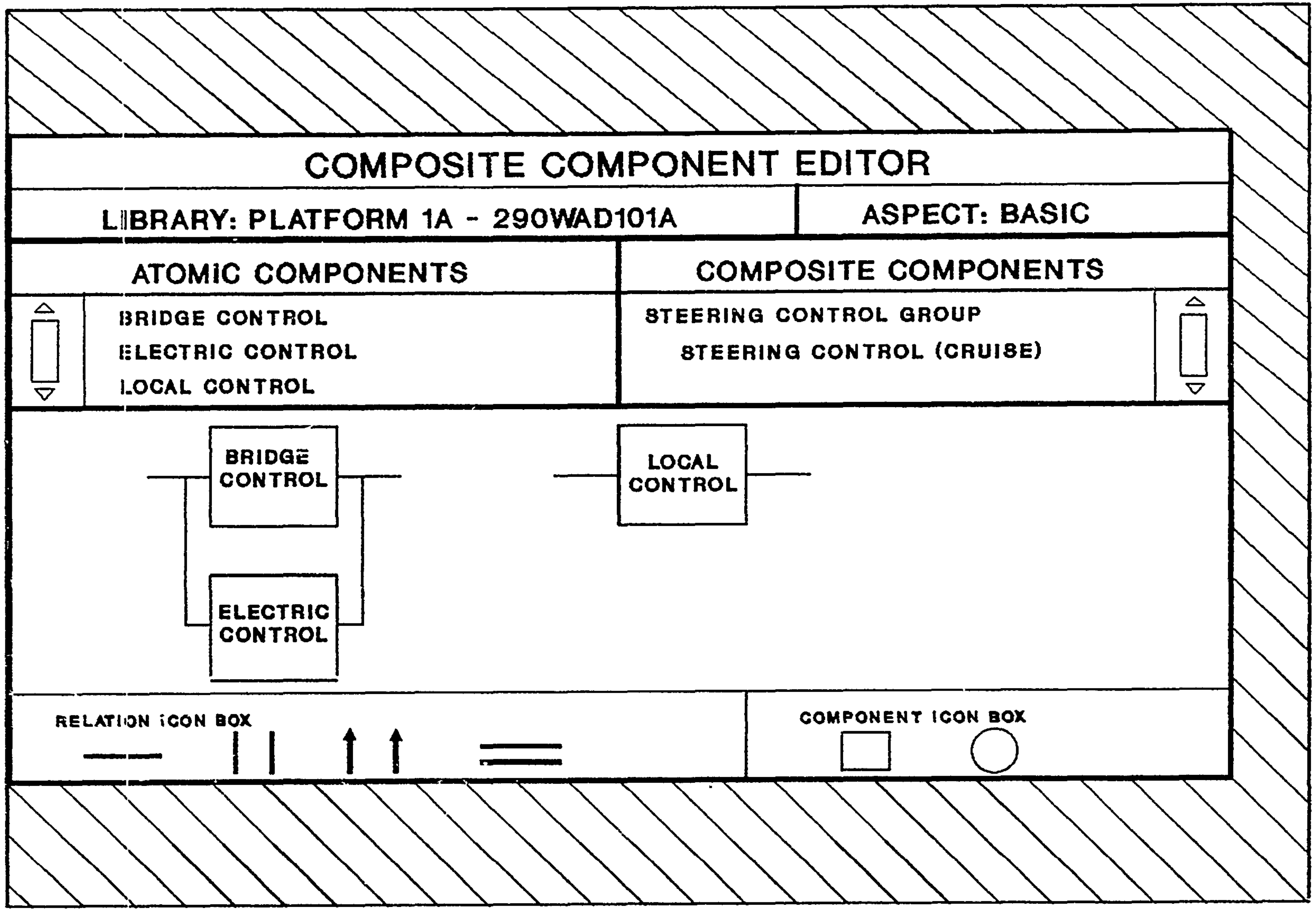


FIGURE 4. EXAMPLE SCREEN: COMPOSITE COMPONENT EDITOR.

FIGURE 5. EXAMPLE COMPONENT DATA STRUCTURES

```
ATOMIC COMPONENT:

NOMENCLATURE:  Bridge Control
VERSION:  290WAD101A
ID:  1
MTBF:  450.0
MTTR:  4.0
DC:  1.0
MTBF-GAMMA:  1
SERIES: (nil, nil)
REDUNDANT:  (nil, Electric-Control-290WAD101A-1)
OPERATION:  Active
REQUIRED:  Yes
     |
     |
     V
NOMENCLATURE:  Electric Control
VERSION:  290WAD101A
ID:  1
MTBF:  550.0
MTTR:  3.0
DC:  1.0
MTBF-GAMMA: 1
SERIES:  (nil, nil)
REDUNDANT:  (Bridge-Control-290WAD101A-1, nil)
OPERATION:  Active
REQUIRED:  Yes

----------------------------------------------------------------

COMPOSITE COMPONENT:

NOMENCLATURE:  Steering Control Group
VERSION:  290WAD101A
ID:  1
COMPONENTS:  (Bridge-Control-290WAD101A-1,
              Electric-Control-290WAD101A-1,
              Local-Control-290WAD101A-1)
NO-REQUIRED:  nil
SERIES:  (nil, Steering-Pump-Group-290WAD101A-1)
REDUNDANT:  (nil, nil)
OPERATION:  Active
REQUIRED:  Yes
```

THE NAVY'S NEW STANDARD DIGITAL SIGNAL PROCESSOR: THE AN/UYS-2

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Abstract

An architectural summary of the AN/UYS-2 multi-processor digital signal processor is presented along with a brief description of the major technologies that are being incorporated into it. Discussion concentrates upon the AN/UYS-2's implementation of data-flow parallel processing to achieve exceptionally high computing throughput rates. In addition, its functional components and the implementation of its hardware functional elements into standard electronic modules are discussed. Supporting this multi-processor architecture is a signal processing graph language methodology called Processing Graph Methodology (PGM) which is used to efficiently and cost-effectively program the AN/UYS-2. Finally, follow-on candidate technologies for infusion into the AN/UYS-2 are highlighted.

LIST OF FIGURES

ABBREVIATIONS

AG	Address Generator
AP	Arithmetic Processor
AU	Arithmetic Unit
BIT	Built-in-Test
BKM	Bulk Memory
CASE	Computer Aided Software Engineering
CBUS	Control Bus
CMOS	Complementary Metal Oxide Semi-conductor
CPP	Command Program Processor
CU	Control Unit
DMA	Dynamic Memory Access
DRAM	Dynamic Random Access Memory
DTN	Data Transfer Network
FBIT	Functional Built-in-Test
FE	Functional Element
FFT	Fast Fourier Transform
FIFO	First-In-First-Out
FIR	Finite Impulse Response
FLOPS	Floating Point Operations per Second
GIGA	Trillion
GM	Global Memory
IO	Input-Output
IOP	Input-Output Processor
ISC	Input Signal Conditioner
MBIT	Module Built-in-Test
MEGA	Million
PE	Processing Element
PGM	Processing Graph Methodology
RALU	Register/File Arithmetic Logic Unit
SBIT	System Built-in-Test
SCH	Scheduler
SEM	Standard Electronic Module
SI	System Interface
SIMD	Single Instruction Multiple Data
SPGN	Signal Processing Graph Notation
SRAM	Static Random Access Memory
SW	Switch
SWC	Switch Controller
VHSIC	Very High Speed Integrated Circuit

INTRODUCTION

Modern warfare depends heavily on processing electronic signals to detect, localize, attack and counter increasingly sophisticated threats. Current Navy signal

processing requirements range from tens of millions to hundreds of millions of multiply-add operations per second. These requirements are expected to increase tenfold within the next ten years. To accommodate these expanding requirements, the U.S. Navy is building the AN/UYS-2 Signal Processor.

The AN/UYS-2 design approach was to develop a "Navy Standard" programmable, modular, multi-processor that could meet a wide range of air, sea and shore signal processing applications into the 21st century. In order to meet this requirement, a hybrid data-flow architecture was chosen to enable evolutionary technology infusion. The AN/UYS-2 architecture consists of a variable combination of multiple types of Functional Elements (FEs), a data transfer network, a control bus, and a built-in-test (BIT) bus. This innovative, fifth-generation computer uses Standard Electronic Module (SEM) - based hardware and a modular organization to achieve the required characteristics of high-throughput, high-reliability, multiple configurations, and reduced software costs.

The essence of the AN/UYS-2 design is a distributed run-time operating system that supports data-flow processing. The latter along with its modular hardware architecture, accommodates the power of a host based software development methodology created to support user signal processing applications development. The host development software utilizes a Navy developed signal processing graph methodology called PGM.

The PGM provides AN/UYS-2 users with a convenient and cost effective way for specifying signal processing algorithms. Using graphics work stations, signal processing engineers express their signal processing applications in the form of "iconic" objective-oriented directed graphs. These iconic graphs are subsequently translated into a PGM source code form called Signal Processing Graph Notation (SPGN). SPGN is, in turn, compiled into object code and downloaded into an AN/UYS-2 for execution.

DATA-FLOW/CONTROL-FLOW PROCESSING

The signal processors presently employed in Navy sensor systems are based upon a time-line control-flow architecture. In such an architecture, processing is initiated by a control signal. This single control signal is the output of a program counter which decodes an instruction stored in memory. A series of instructions along with their respective data represent the computer program to be processed. Normally program execution and the output, a single control signal, is a sequential process. In a multi-thread control flow architecture one or more control signals is provided. Such an architecture may achieve parallel processing via a single central sequence of instructions which are carried out simultaneously on many processors and data streams. Control-flow is a highly efficient means of executing concurrently on multiple processors if the process can be described in a do-loop like statement. Unfortunately, not all processors exhibit this characteristic and it is difficult to write programs as simplified operations that can be applied to multiple data streams. An alternate to control-flow is data-flow.

In a classical data-flow organization, an instruction/task is executed when machine resources and input data become available. Sequencing is performed by the flow of data in an asynchronous manner. There are no program counters or central control. All input data is consumed and the output results passed directly to subsequent instructions as input data. This differs from single-thread control-flow architecture in two significant ways: first, data exists only during the interval between its production and consumption, therefore requiring no fixed address associated with a particular datum in a sequential memory; and secondly, the control unit requires no program counter to address instructions sequentially in memory. Since any task may be executed when its inputs are available, concurrent processing is easily and naturally supported. There are two major problems which detract from the simplicity of data-flow. First, the cost of communication and bookkeeping operations are significant, and secondly it is difficult to schedule tasks such that the work load is evenly distributed over all processors.

While these two approaches are seemingly different and conflicting, the attributes of data-flow and control-flow can be complementary if properly implemented within a computer architecture. If one uses data-flow at the task or functional level rather than at the elementary level used in traditional data-flow, the costs associated with communication and bookkeeping are minimal compared with the gain in concurrent processing. Control processing within the task provide efficient execution at the fine grain or elementary operation level. The AN/UYS-2 implements such an architecture. It has implemented a modular hardware design along with a distributed run-time operating system, that incorporates a hybrid data-flow and control-flow program organization to realize high throughput and utilization of computational resources. The architecture employs: 1) data-flow at the task level to exploit the parallelism inherent in signal processing applications; 2) control-flow processing within the processing elements to eliminate the communication and bookkeeping costs that data-flow would incur at the fine grain (elemental operation) level; 3) decentralized scheduling and control; and, 4) intelligent control within each processing element to monitor and control work loads.

AN/UYS-2 ARCHITECTURE

The AN/UYS-2 architecture encompasses a diverse family of modular machine configurations which are tailored to meet the specific processing and packaging requirements of a given application. This versatility is realized by defining a set of autonomous and asynchronous functional elements (FEs) which form the basic system building blocks, see Figure 1. Each functional element uses the same protocols and electrical interfaces. The functional elements are, in turn, constructed from a set of Standard Electronic Modules (SEMs).

Modularity in hardware and efficient support of technology evolution requires an application software interface that isolates programming from configuration change or upgrade, as well as, supporting data-flow execution. The signal processing graph methodology that has evolved as the logical means of expressing data-flow programs appears to provide such an interface. The Navy-sponsored Processing Graph Methodology (PGM) with its Signal Processing Graph Notation (SPGN) is used to program an AN/UYS-2. Data-flow programs are expressed as processing graphs that are analogous to flow diagrams commonly employed as high level summaries of the signal processing flow. Using PGM, the application developer describes a set of processing graphs, where each graph makes use of a collection of pre-defined signal processing functions (primitives). Figure 2 provides a simple processing graph example. The circles are nodes, the basic signal processing entity of PGM. Nodes are serviced by the signal processing primitives. The directed lines represent first-in-first-out (FIFO) data queues (buffers). Queues provide the primary data storage and transfer medium for processing graphs.

As stated before, an AN/UYS-2 system is implemented through a collection of FEs. Each FE is a functionally complete architectural component supporting hardware and software functions necessary to perform its assigned tasks. The FE types were carefully selected to provide a balanced distribution of work load and control. Currently, six FE types are defined. the Arithmetic Processors (APs), the Global Memories (GMs), the Scheduler (SCH), the Command Program Processor (CPP), the Input/Output Processors (IOPs) and the Input Signal Conditioner (ISC). Support of technology infusion is provided by formal management of FE communication interfaces. A new FE, or alternate realization of an existing one, can be integrated provided it uses the AN/UYS-2 protocol and electrical interface.

Communication between FEs is supported by the Control Buses (CBUSs) and the Data Transfer Networks (DTNs). The control buses are used to communicate control data, data requests, and test functions. The DTN is a dynamically reconfigurable, non-blocking matrix switch for the movement of data queues between FEs.

DATA-FLOW SIGNAL PROCESSING SCHEDULING AND CONTROL

The AN/UYS-2 views a node at the signal processing task or functional level. Unlike traditional data-flow architectures which schedule elemental (add, multiply) operations on a single operand or operand pair, AN/UYS-2 uses data-flow to schedule macro functions such as a matrix multiply or Fast Fourier Transform (FFT). Since these functions may operate on arrays of hundreds or thousands of operands, the scheduling and bookkeeping is reduced by several orders of magnitude over data-flow at a fine grain level, by only one scheduling at the functional (macro) level.

A bonus of the task level data-flow control is the direct mapping between a signal processing and a data-flow graph. In the PGM data-flow program description, signal processing applications are defined as a directed graph, with the nodes representing signal processing functions such as FFT and Finite Impulse Response (FIR), and the arcs representing the flow of data between nodes. Conversion of this graph into an executable data-flow graph involves little more than defining read, produce, and consume amounts, defining the threshold amount of data in each queue required to dispatch the target node, and adding any needed synchronization nodes.

Most signal processing nodes are highly repetitive loops operating on one or more arrays of data. The parallelism in these operations can be described for the most part by simple loop constructs, amenable to control-flow. AN/UYS-2 uses control-flow techniques (SIMD and pipeline processing) to exploit this parallelism, thereby eliminating the burden of communication and bookkeeping that data-flow would incur at the micro level.

The Arithmetic Procesor in AN/UYS-2 contains a control processor, denoted Control Unit (CU), to act as a local task dispatcher. At any given instant, several nodes may be in various stages of processing within the element. For example, the CU may have dispatched the output of one node, while the data from a second node is being processed, and data from a third node is being read. Once the output of the first node and the computation of the second node is completed, the CU will request a new task. The overlapping of setup and breakdown leads to a balanced system in which all processing elements share equitably in the processing of a graph.

The data-flow scheduling and control of nodes is distributed between a Scheduler, the Global Memories, and the Processing (Arithmetic Processor) Elements. The Global Memories (GMs) maintain data queues (graph arcs) and report on their status. Each data queue is a dynamic structure with an associated threshold and capacity. The queue threshold indicates the minimum number of data elements needed to satisfy one of the conditions for a node firing. When the number of elements in a given queue reach or exceeds threshold, a queue-over-threshold message is sent to the Scheduler. No further threshold messages are sent until the queue has been consumed and its contents again exceed threshold. Each queue has a capacity above which an queue-over-capacity message is sent to the Scheduler. This inhibits the input node from firing until the queue falls below capacity and a queue-under-capacity message is sent to the Scheduler.

The Scheduler's primary function is to determine when a node is ready-to-execute and to match it to a free processing element (PE). A node is ready-to-execute when all of its input queues are above threshold and all synchronization events are satisfied. The Scheduler performs these tasks via four tables: the queue-to-node table, the node status table, the ready-node list,and the free PE list.

The queue-to-node table is a connectivity map which identifies the input and output nodes associated with a given queue. This map points to entries in the node status table. Each node entry in the node status table contains the node's identification (id), priority, firing counter, instruction stream location, and graph instance. The firing counter indicates the number of conditions (queues-over-threshold synchronization events) that remain to be satisfied before the node can fire. As each of these conditions is satisfied, the firing counter is decremented. When the counter reaches zero, it is matched to a processor on the free processor or placed on the ready-node list if no free processor is available. Nodes on the ready-node list are matched to free processors, as they become available.

Once the Scheduler has matched a node to a free PE, it obtains the node's instruction stream id from the node status table and sends a message to the Global Memory containing the instruction stream. It then increments the firing counter by the number of conditions needed to fire that node again.

At this point, the Scheduler has essentially completed its tasks. The GM receives the message, locates the instruction stream, and forwards it to the designated PE. The instruction stream contains information on what data is needed to execute the node, where it is stored, and what operations are to be performed. For example, it might instruct the PE to fetch 1024 data elements each from X and Y (stored in GM #i and #j respectively), to store these inputs in specific locations in operand memory, to perform a vector multiply, and store the results in queue Z in GM #k. It would then instruct the GM to consume X and Y.

The instruction stream is decoded by the PE. It forwards request for the data needed to execute this node (to the GMs) and stores the data in an operand memory as it is received. After a node has executed, a message is sent to the Scheduler, causing the sending PE to be placed on the free PE list. Since a PE overlaps setup and breakdown with execution, a new node is typically setup and awaiting execution.

It should be noted that a second instance of the node cannot fire until the first has completed. This prevents data from getting out of sequence and simplifies error recovery. Also, once a queue sends a queue-over-threshold message, it cannot send another until it has been consumed (zero consume is permitted). This insures that queue cannot send multiple queue-over-threshold messages and prematurely fire a node.

Any node can be suspended or inhibited by sending a message which increments its firing counter. For example, if a given queue is nearing its maximum capacity, a queue-over-capacity message inhibits the input node for that queue. When the queue falls below capacity, a queue-under-capacity message is sent and the firing counter is decremented. Similarly, messages to suspend and start a given node or node sequence will increment and decrement the firing counter respectively.

FUNCTIONAL ELEMENT CHARACTERISTICS

As stated before, the AN/UYS-2 architecture consists of a variable combination of six types of Functional Elements (FEs), a Control Bus, a Built-in-Test (BIT) bus, and an optional Input Signal Conditioner. Since the control and support functions provided by the run-time software operating system are distributed throughout the AN/UYS-2, each functional element is loaded with a program which performs the functions assigned to that element, and also communicates with other functional elements via the control bus.

There are two Standard Electronic Module (SEM) type implementations of the AN/UYS-2 FEs. The present available SEM version of the AN/UYS-2 is the format "B" type which is in production. Concurrently, the AN/UYS-2 is being repackaged into SEM E format modules, see Figure 3, which optimizes the system for use in aircraft applications in terms of weight, size and

power performance factors. This repackaging has resulted in a forty (40) percent savings across those factors, as well as a corresponding improvement in reliability. An additional benefit realized by changing the SEM form factor has been the reduction in the unique SEM count in the basic architecture from forty-four (44) in the SEM B to only ten (10) in the SEM E format. Besides increasing commonality across the functional elements, fewer unique SEM types will have a significant impact upon reducing the costs associated with spares, depot and in-service engineering support. The following discussion pertains to the functional elements as implemented in the SEM E format. Of particular interest to the reader is the use of available state-of-the-art microcircuit devices and commercial off-the-shelf processor technology.

The Command Program Processor (CPP) is assigned the functions of tactical interface, sensor input/output channel configuration control, data-flow graph management, and overall system error performance monitoring. This CPP has been implemented using an off-the-shelf Motorola 68020 processor in conjunction with a Motorola 68881 floating point co-processor, both are packaged on one Central Processing Unit (CPU) SEM. In addition to that SEM there are three others, namely: Bulk Memory (BKM) SEM, System Interface (SI) SEM and Input/Output (IO) SEM. The CPP has the following performance characteristics: 20-megahertz clock rate, 32-bit data bus, and 32-megawords (16-bit per word) storage capacity. Another feature is that the CPP is Ada programmable.

The Input/Output Processor (IOP) is used to input raw digitized sensor data into, and output processed data from, the AN/UYS-2. As input data is received by the IOP, it is formatted and provided to the Global Memories via the Data Transfer Network, as described later. Output data is received from the Global Memories and provided to external channels by the IOP. The IOP is implemented using the same commercial processor as the CPP with the same performance features. An IOP is capable of handling up to fifteen input-output channels with a total capacity of 5-megahertz in 16-bit data word format.

The Data Transfer Network (DTN) is a unidirectional source-directed crossbar data switch between the GMs, APs and IOPs. Since the DTN data switch is non-blocking, up to 16 asynchronous 32-bit data transfers may occur simultaneously. The data sources are continuously polled by the DTN, and when a source requests a destination which is not already receiving data, the path is established and the data transfer is accomplished. The DTN is also used for initial loading of the functional elements and distribution of the graph instance data. A DTN may be configured with 2, 4, 8, or 16 input and output ports. Each port may be expanded by a concentrator (at an input port) or a distributor (at an output port) which provides four-in/four-out through the ports. Independent transfers may occur simultaneously on as many paths as there are input-output port pairs, and each transfer can be at a maximum rate of 20 million 16-bit words per second (limited only by the slower of the source and/or destination processing element transfer rates).

The DTN is physically implemented by a common multilayered backplane with an embedded data transfer network, and two types of SEMs. One of these is a Switch Controller (SWC) SEM and the other is a Switch (SW) SEM. Only one SWC SEM which is programmable is required for as many as seven SW SEMs. The number of SW SEMs determines the DTN configuration with regard to the input ports and output ports of the DTN. There are four typical configurations for the DTN, those being: DTN 16 (16x16), DTN 8 (8x8), DTN 4 (4x4), and DTN 2 (2x2). The latter configurations support the following respective number of FEs, using a combination of SEMs (SWC and SW) as indicated, in parenthesis: 32 (1-SWC/7-SW), and 16 (1-SWC/4-SW), 8 (1-SWC/2-SW), and 4 (1-SWC/1-SW).

The Arithmetic Processors (APs) are the functional elements which perform the actual signal processing functions. When a function (node) is scheduled by the Scheduler, the AP is provided the command necessary for it to read appropriate input data from the Global Memory (GM), execute the appropriate algorithms, and write the resulting data back to the GM. An AP may queue up to three nodes concurrently for processing. A node then may be in either one of three possible processing phases: setup, execution or breakdown. When an AP has completed execution of a node, the AP informs the Scheduler that it is prepared to accept another node for setup while simultaneously executing a node from a previous setup phase. Since each AP can execute a processing task, the next node provided to the AP may be from the same particular data-flow graph or from another unrelated graph running concurrently within the AN/UYS-2 ensemble. It is this concept of using a parallel set of resources asynchronously that allows nodes to execute when data is available, with minimum loss of throughput due to the unavailability of resources.

Each AP in an AN/UYS-2 has four parallel arithmetic pipelines (based upon AT&T DSP-32C type processors), each pipe is provided with one floating point multiplier and two adders. The pipes process 32-bits of floating point data each cycle, and conform to the IEEE754 floating point processing standard. From a raw processing perspective and at 10-megahertz clock rate, each pipe is capable of 30 million multiply-adds per second or million floating point operations per second (MFLOPS).

In total each 4-pipeline AP is capable of 120 MFLOPS, which yields a very high signal processing throughput rate, see Figure 4. Another aspect of the AP is that in April, 1987, this FE was part of a successful VHSIC Phase I insertion demonstration. The Register Arithmetic Logic Units (RALUs) that implement the adders for each pipeline were implemented using 1.25 micron CMOS logic gate array technology. Potentially, the APs can operate at 25-megahertz clock rate which would more than double their throughput to an exceptional 300 MFLOPS. The SEM E format APs also use 256K Static Random Access Memory (SRAM). To implement an AP functional element requires three SEM E format cards, see Figure 5, as follows: a Control Unit (CU) SEM, Address Generator (AG) SEM, and the Arithmetic Unit (AU) SEM. Figure 4 provides a diagrammatic overview of an Arithmetic Processor functional element AU SEM, illustrating its technology, performance and processing attributes.

The last two AN/UYS-2 functional elements are the Global Memory (GM) and Scheduler (SCH). Both of these FEs are implemented using the same hardware components. A Common Control Unit (CCU) SEM, which is the same as that in the APs, and a Bulk Memory (BKM) SEM are all that is required to implement either of these FEs. Likewise, the performance characteristics are the same for both FEs. The GM/SCH functional elements execute at a 10-megahertz clock rate and can be configured with up to 16-megawords (16-bits/word) of Dynamic Random Access Memory (DRAM) using the latest off-the-shelf 4-megabit DRAM chip technology. Typically, a SCH would only be configured with 1-megaword of DRAM. Another feature of the DRAM is that the Error Detection and Correction circuitry provides: 1) single bit error detection and correction, and 2) double bit error detection. The GM/SCH functional elements also support a 32-bit data transfer bus with DTN burst transfer rates of 20-megawords (16-bit/word) per second. These transfers are full Dynamic Memory Access (DMA) types with crosspoint transfers. The following two paragraphs explain the functional operations of both the GM and SCH functional elements.

The Global Memory (GM) is used to store signal and control data, manage the storage resources, and establish when a predetermined threshold of data has accumulated on a queue for nodes to be ready to execute in an AP. As data are added to a queue by the APs and IOPs, the GM monitors the amount of data present on the queue and compares it to the amount of data necessary for the node to execute. When this threshold value is reached, the GM informs the Scheduler that the queue has exceeded threshold. When data is used (consumed) by a node, the GM frees the available storage resources and may report to the Schedule that the queue still has enough data for a node to execute. In addition to providing the resources and services for signal data storage, the GM also retains the control variables needed by the nodes as well as the information which is transmitted to the APs to identify the specific data to be processed and associated task(s) to be executed for each specific node.

The Scheduler (SCH) is the functional element which determines the "readiness" of the nodes and assigns them to available resources. This function can be viewed as two separate operations. Event Processing involves the reception of information from the GM that queues have exceeded threshold and from processing elements that nodes have completed execution and resources are available. The Match Processing function "matches" nodes that are ready to execute with available resources that are capable of executing the node. As queue threshold events are received by the Scheduler from the GMs, Event Processing updates the appropriate databases, and determines when all input queues of a node have exceeded their thresholds. When this occurs, and if the node is not already executing, Match Processing then assigns the node to an available resource and requests the Global Memory containing the control information for that node to transmit that information to the selected processing element. When a Processing Element informs the Scheduler that it is available for another node, the Scheduler checks for any nodes that are waiting for execution and assigns them to the newly available resource.

The sixth functional element that may be incorporated into an AN/UYS-2 configuration is an optional Input Signal Conditioner (ISC). An ISC translates analog signals into digital ones for processing by the AN/UYS-2. It is specifically tailored to meet the requirements for input and sonobuoy uplink, output to sonobuoy downlink, tape records and aural monitoring lines. In terms of performance, on ISC is capable of handling sixty-four (64) channels of analog data. Associated with each channel is a single Texas Instruments, Inc. TMS320C25 based processor, which operates at an 8-megahertz clock rate processing digitized data (converted analog to 16-bit fixed point) from its respective input channel. The processor performs two adds and one multiply per clock cycle yielding a throughput processing rate of 24-megaFLOPS per channel per second. In aggregate, an ISC has a significant processing potential of over 1.536-gigaFLOPS per second.

A discussion of the AN/UYS-2 functional elements would not be complete without mentioning the Control Bus (CBUS) and the Built-in-Test (BIT). The CBUS is the means by which the functional elements communicate data-flow control information between one another. This is accomplished via the mail-boxing of messages between each of the functional elements personalized

software operating systems. The CBUS is used for those communications that do not require large data blocks; the latter are transferred using the DTN.

As for the BIT feature of the AN/UYS-2, it is implemented at three different levels within the architecture. Each SEM Card has a Module Built-in-Test (MBIT) capability which when triggered reports to a Functional Built-in-Test (FBIT) controller at the FE level. This occurs for each set of SEM Cards implementing an FE. Each FBIT in turn, when triggered by error condition, reports to the System Built-in-Test (SBIT) which is a functional part of the Command Program Processor. The BIT function communicates between each of the three respective levels: MBIT, FBIT and SBIT, are handled via the BIT Control Bus (BIT CBUS). Both the CBUS and the BIT CBUS are 8-bit wide parallel bus implementations.

APPLICATION DEVELOPMENT ENVIRONMENT

The AN/UYS-2 has been designed to implement a Navy developed, high-level signal processing software development methodology called Processing Graph Methodology (PGM). The implementation of PGM on AN/UYS-2 provides the AN/UYS-2 user with a convenient way of specifying signal processing algorithms in the form of signal processing data-flow (directed) graphs, see Figure 2. PGM graphs are analogous to flow diagrams commonly employed as high level summaries of the signal processing flow. Through Navy sponsored research, the use of data-flow graphs has been shown to be a highly effective and efficient means for mapping the signal processing application onto a parallel multiprocessor data-flow architecture, such as the AN/UYS-2. Implementing a Computer Aided Software Engineer (CASE) environment which supports the application developer programming the AN/UYS-2, by providing a broad range of software development tools.

The CASE tools have been implemented across a VAX(1)/UNIX(2) and SUN(3)/UNIX(2) Workstation development environment. This development environment allows the user to proceed logically from the "iconic" (graphics) data-flow diagram generation through load-image download and execution on an AN/UYS-2. Developing an AN/UYS-2 application would follow a basic four to five step process. The application developer begins by generating a graphical representation of this data-flow graph, see Figure 2, using tools hosted on the SUN(3) workstations, see Figure 6. Once the graph is completed the developer then automatically converts the iconically created graphs into a Signal Processing Graph Notation (SPGN) High Order Language to form a compilable representation of the application, see Figure 6. With this SPGN representation a developer can then translate the graph into an executable form whereby one of several functions can then be performed. These functions include: 1) static graph analysis, 2) event-time simulation (to derive timing, capability, and sizing statistics), and 3) graph optimization, see Figure 7. Once the developer is satisfied with his application at this point, he transports the SPGN form of the application onto the VAX(1)/UNIX(2) host to continue with development. While on the host the developer may compile the SPGN into an executable form targeted to an emulator which performs the signal processing numeric computations using the VAX processor, see Figure 8. Thus, an application developer derives numerical outputs from the VAX for validation of the actual AN/UYS-2 output. In addition to these capabilities, the HOST tools provide load image preparation, linkage and download capability, see Figure 9. With the latter the application developer takes the translated SPGN code and directs the system to automatically link into that code the signal processing primitives,from a library, as specified by the "nodes" in the graph. Once this signal processing graph load image has been produced, the AN/UYS-2 distributed run-time operating system is merged with it and together they are downloaded onto the AN/UYS-2. Finally, with the completion of the downloading process, the VAX/UNIX based tools are employed to initiate AN/UYS-2 execution and processing. The AN/UYS-2 procesing may be performed on either real or simulated data. Furthermore, the AN/UYS-2 execution and signal processing can be controlled interactively to allow for testing and debug, see figure 10. The combination of both SUN workstation and VAX host tools form the basis for an impressive "holistic" signal processing software engineering environment.

(1) VAX is a registered trademark of Digital Equipment Corporation (DEC)

(2) UNIX is a registered trademark of AT&T

(3) SUN-3 is a registered trademark of SUN Microsystems, Inc.

TECHNOLOGY INSERTION

The AN/UYS-2 has already incorporated several state-of-the-art technologies into its architecture, including Very High Speed Integrated Circuits, large DRAMs and SRAMs, and commercial Motorola processors. In addition to these, the software application development CASE environment uses a commercially (Telesoft Inc.) available ADA(4) compiler and a run-time exective (ARTX-Ready System Inc.) for the target MC68020. Another technical improvement to the AN/UYS-2 attributable to SEM E repackaging, is the use of Applica-

AN/UYS-2 PARALLEL MULTI-PROCESSOR DATA-FLOW ARCHITECTURE

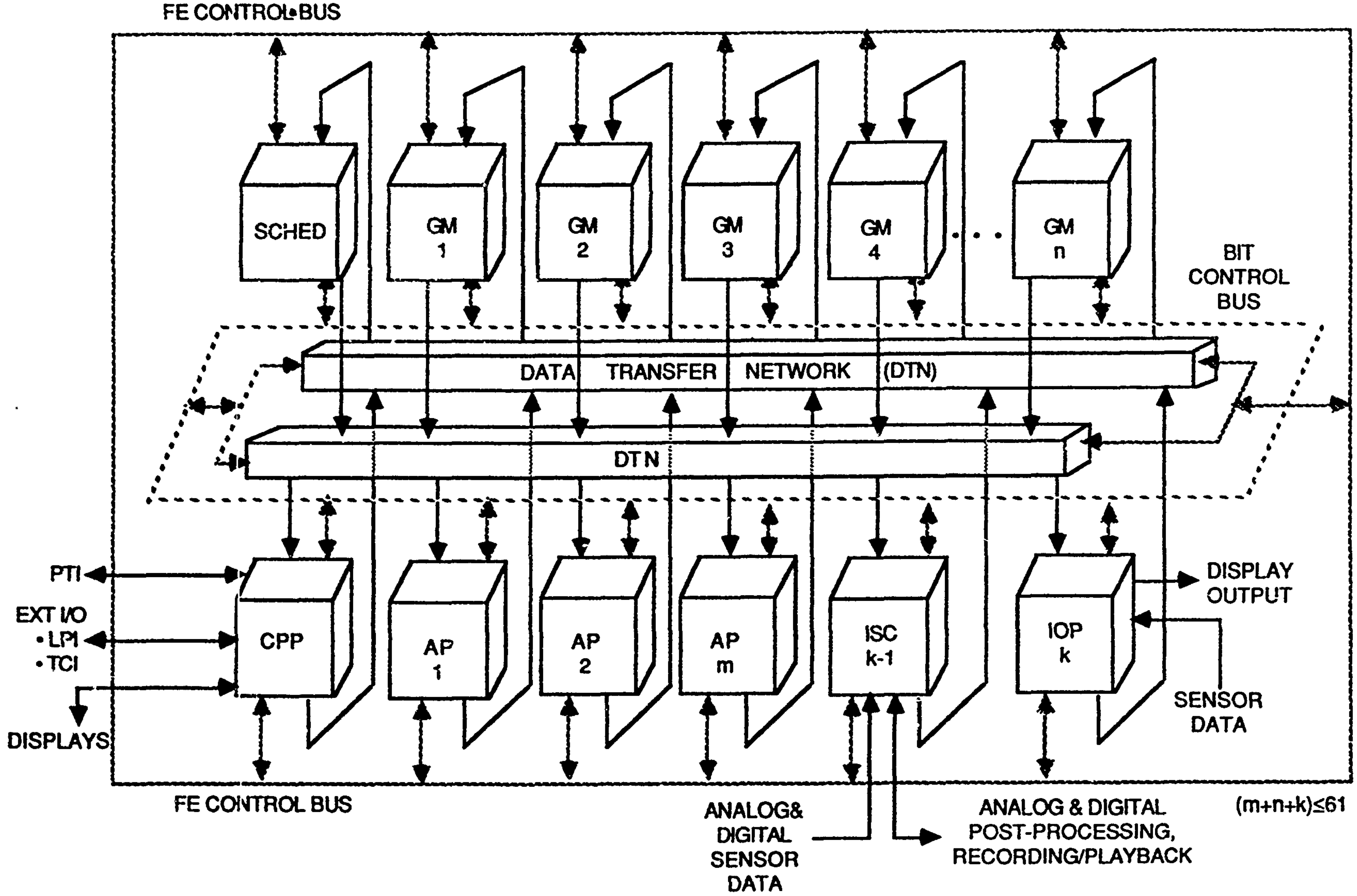


FIGURE 1.

AN/UYS-2 (GRAPHICAL) PGM PROGRAMMING

PGM GRAPH

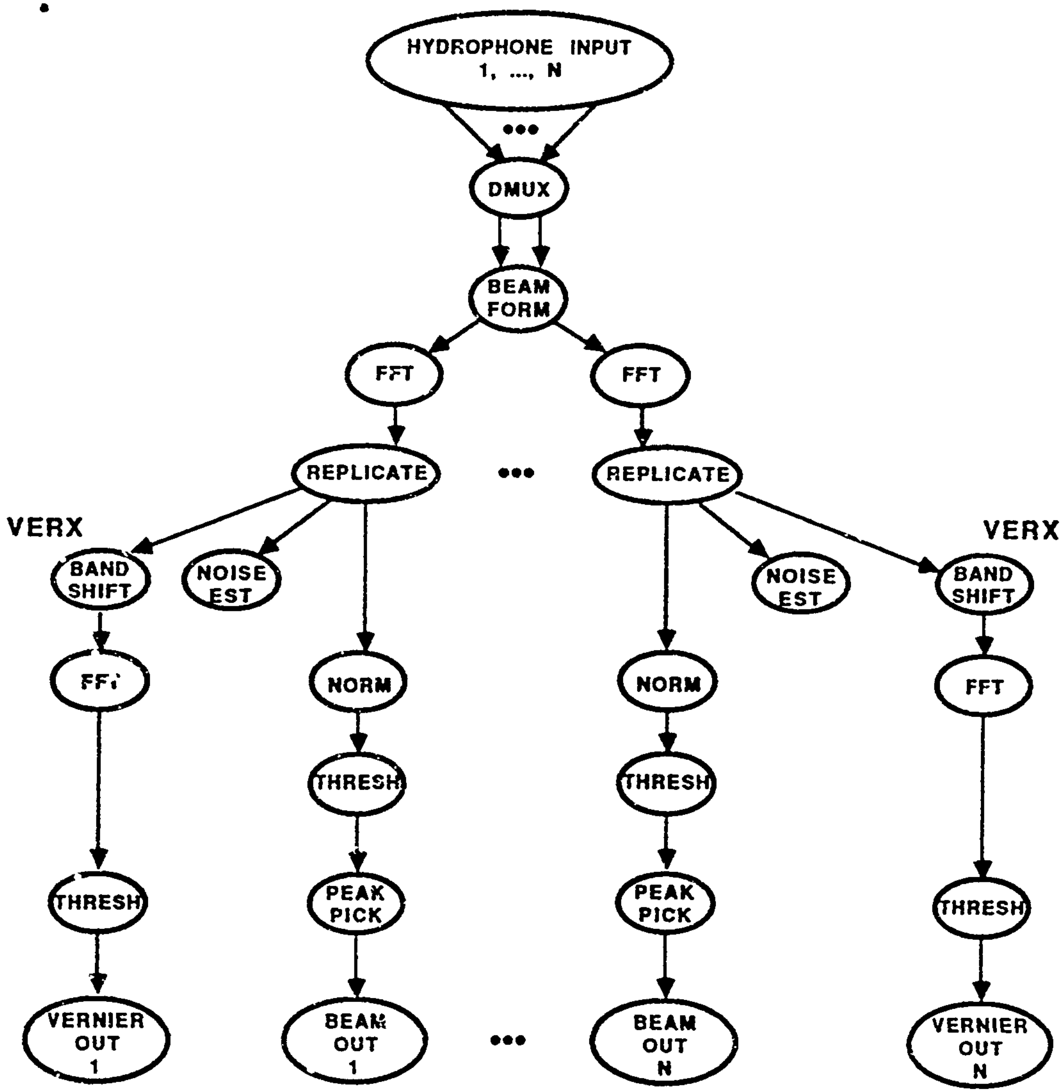


FIGURE 2.

AN/UYS-2 (GRAPHICAL) PGM PROGRAMMING

PGM GRAPH

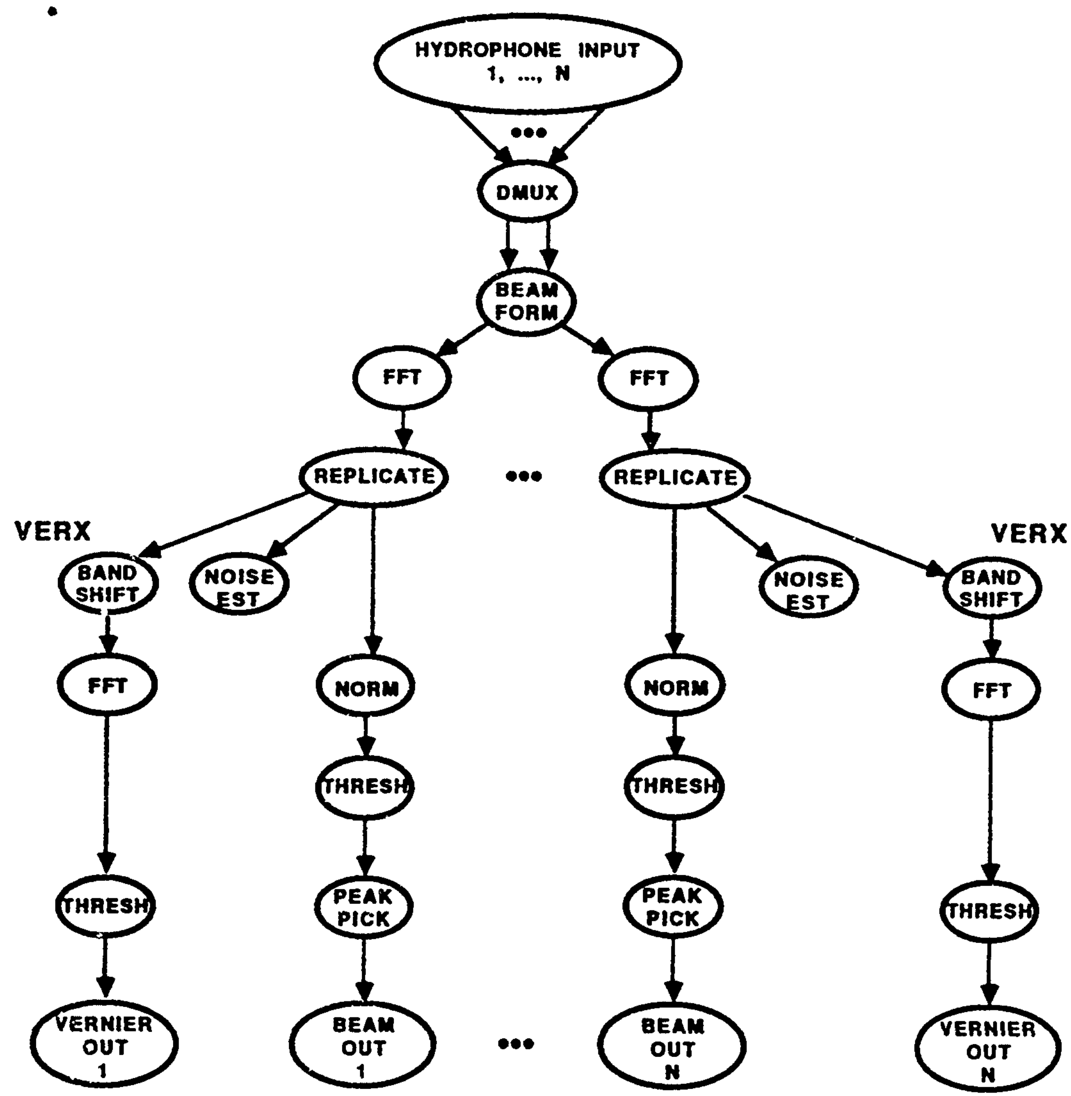
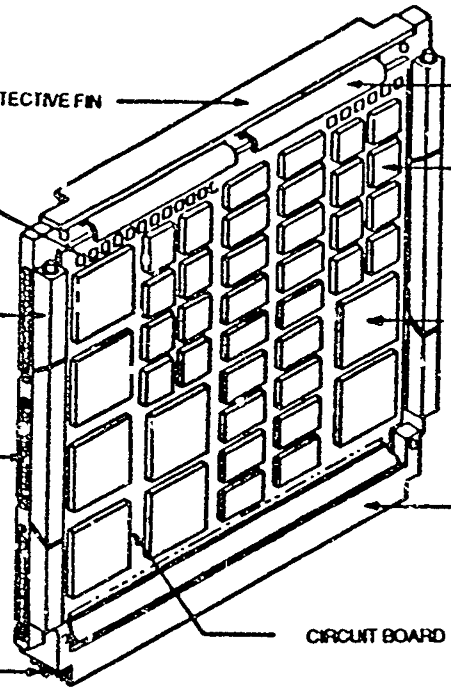


FIGURE 2.

SEM E PHYSICAL DESIGN



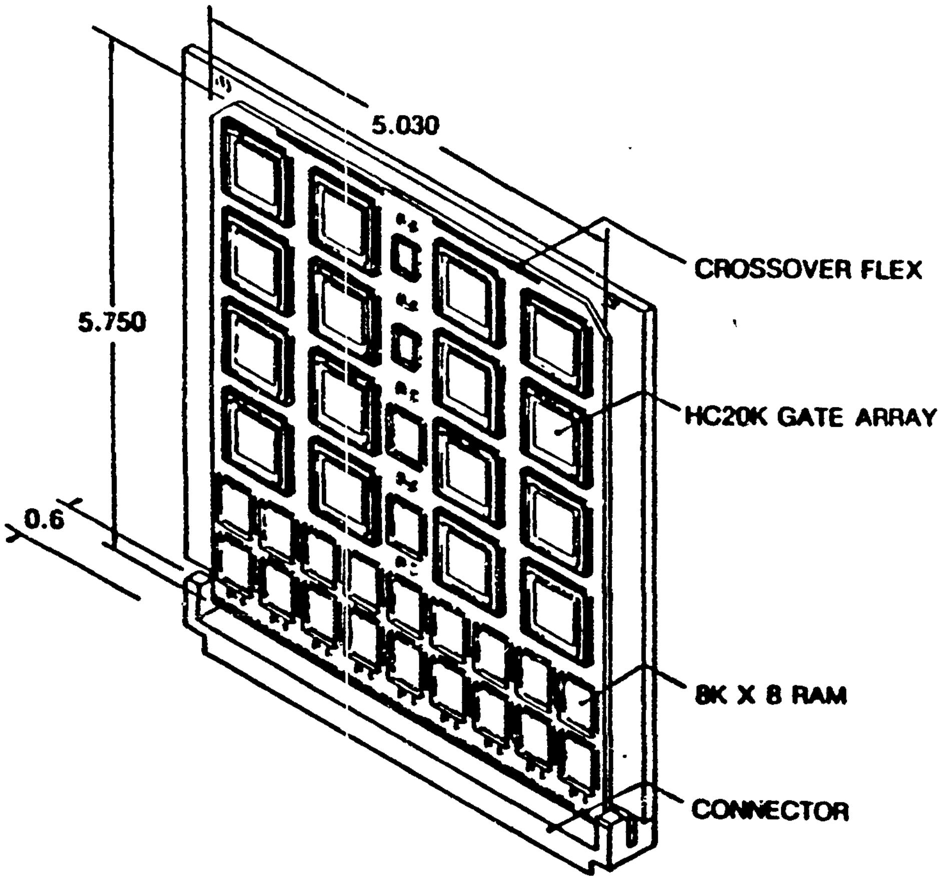
SEM THICKNESS	
COATING	0.001 INCH
CHIP CARRIER	0.095
STAND OFF	0.040
CIRCUIT BOARD	0.055
ADHESIVE	0.004
SEM FRAME	0.175
ADHESIVE	0.004
CIRCUIT BOARD	0.055
STAND OFF	0.040
CHIP CARRIER	0.095
COATING	0.001
TOTAL	0.565

SEM WEIGHT		
DEVICES	135	GRAMS
CIRCUIT BOARDS	100	
CONNECTOR	28	
WEDGES	35	
FLEX CIRCUIT	5	
FRAME	260	
TOTAL	563	GRAMS
	1.25	POUNDS

SEM DIMENSIONS		
SPAN	5.880	INCHES
HEIGHT	6.680	INCHES
THICKNESS	0.565	INCHES

FIGURE 3.

ARITHMETIC PROCESSOR:
ARITHMETIC UNIT MODULE



- o TECHNOLOGY
  - VHSIC (1.25u) CMOS ICs
  - ASIC (0.9-1.25u) CMOS ICs
- o PERFORMANCE
  - 40 WATTS
  - 10 MHz RATE (25 MHz POTENTIAL)
  - 120 MFLOPS (32 BIT FLOATING PT) PER AP
  - FULL DMA XFER
  - 4 FFTs (1024) PER 2mSECS OR 1 FFT PER 500uSECS
- o 32 BITS NUMERICAL PROCESSING
  - RANGE: -10^{-38} TO $+10^{38}$
  - MANTISSA (FRACTIONAL): 23 DATA BITS/1 SIGN BIT
  - CHARACTERISTIC (EXPONENT): 8 BITS
  - IEEE STD 754 FORMAT

FIGURE 4.

ARITHMETIC PROCESSOR FE SEM ARCHITECTURE

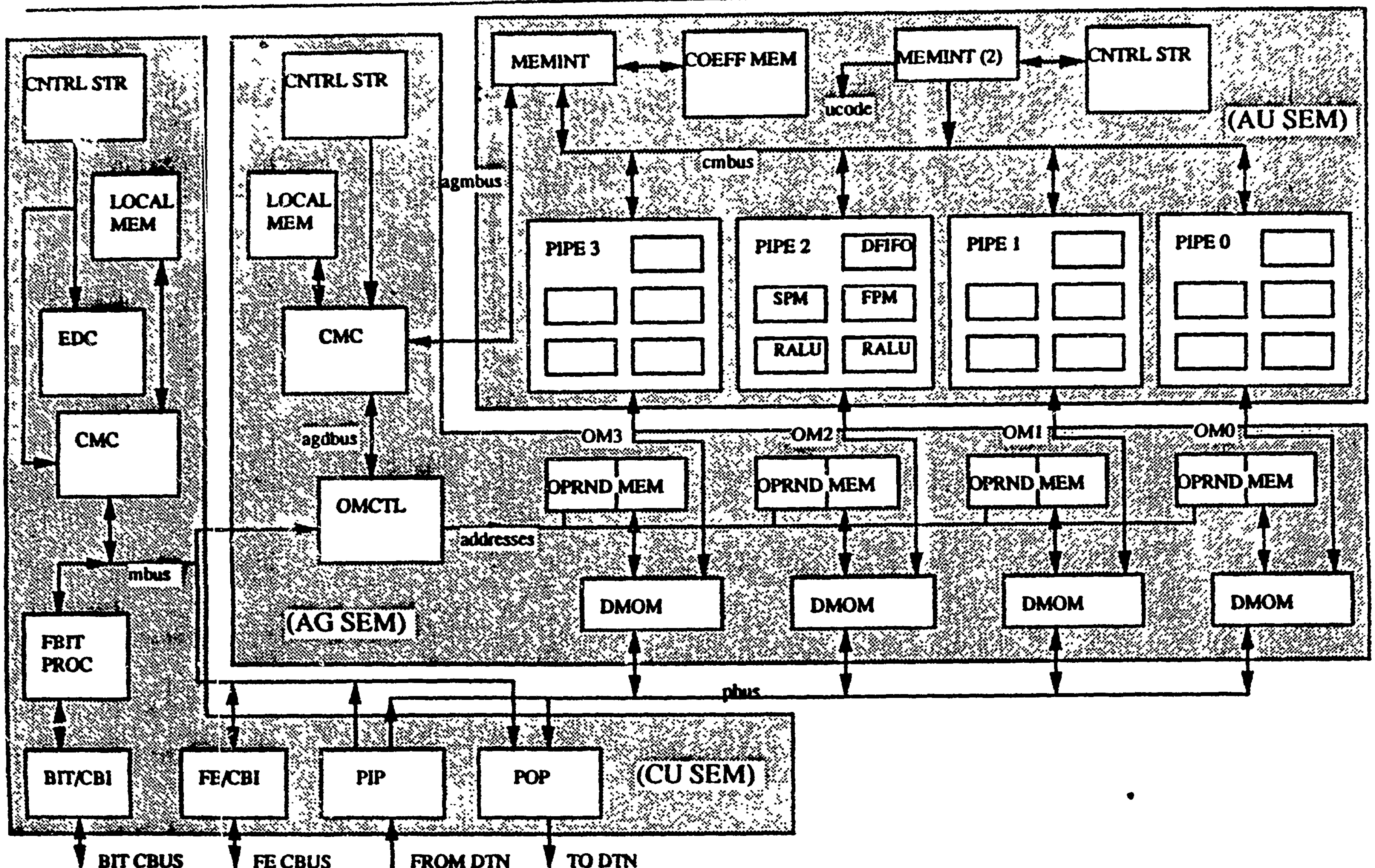
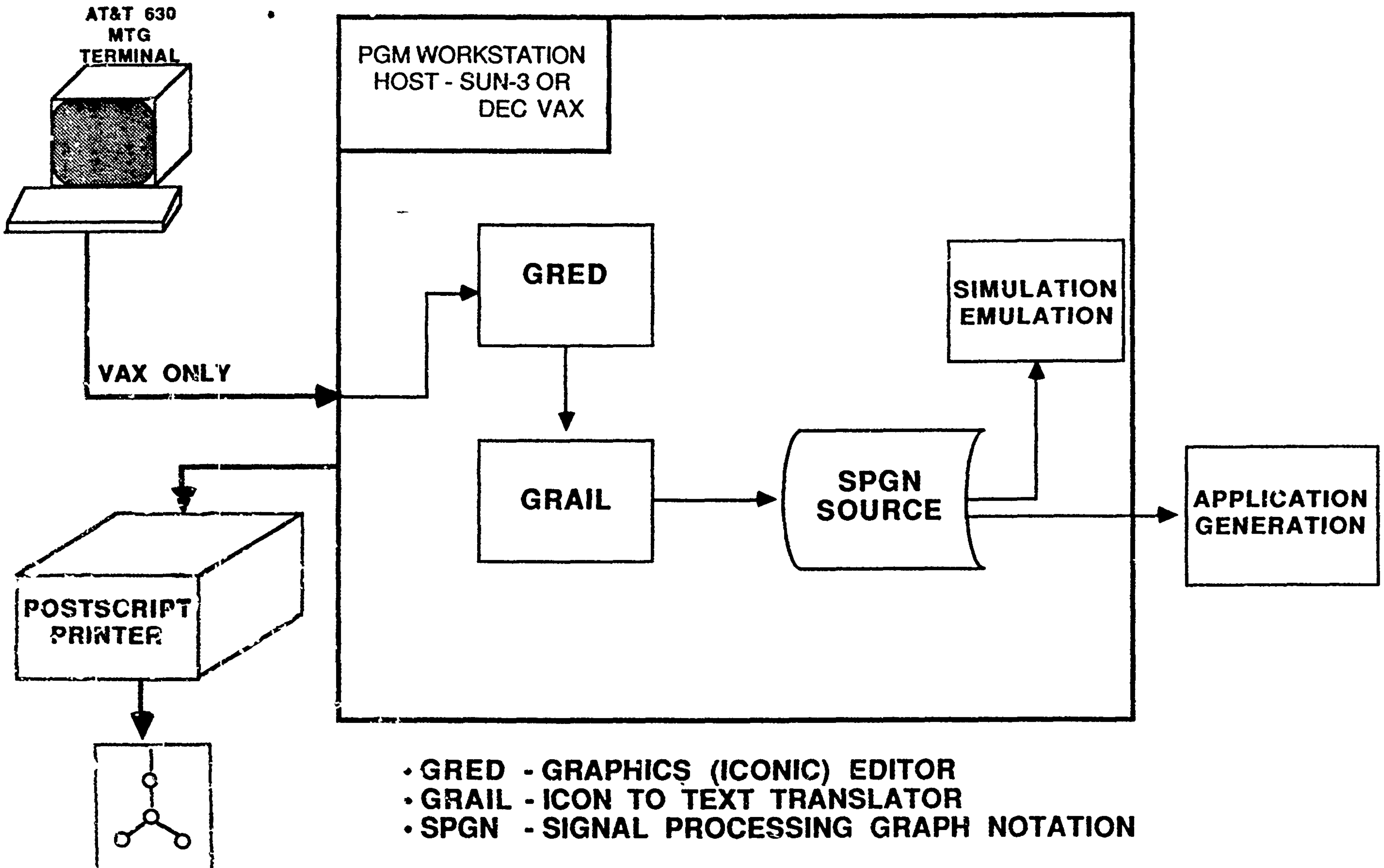


FIGURE 5.

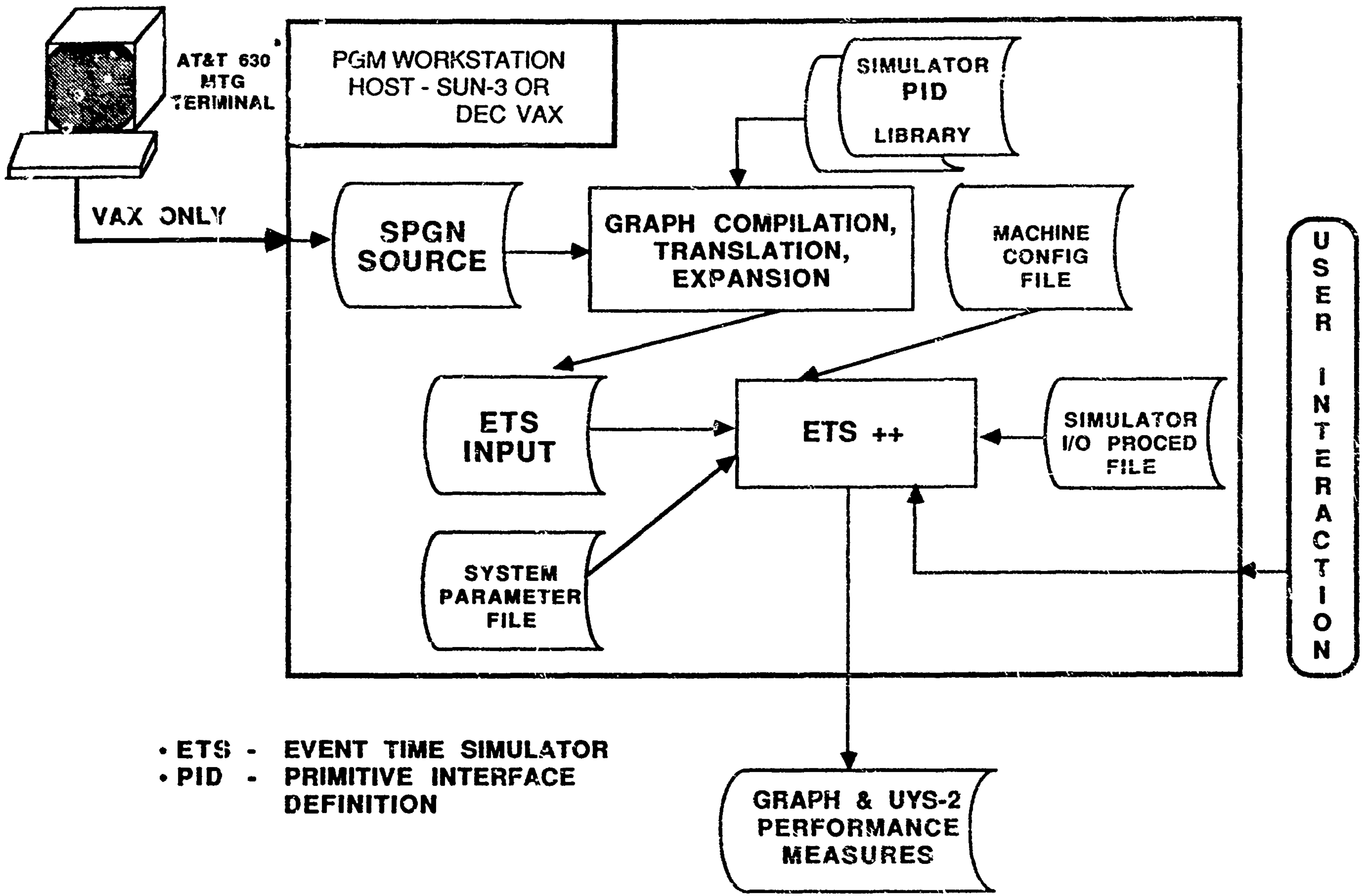
GRAPH GENERATION (ICONIC)



- GRED - GRAPHICS (ICONIC) EDITOR
- GRAIL - ICON TO TEXT TRANSLATOR
- SPGN - SIGNAL PROCESSING GRAPH NOTATION

FIGURE 6.

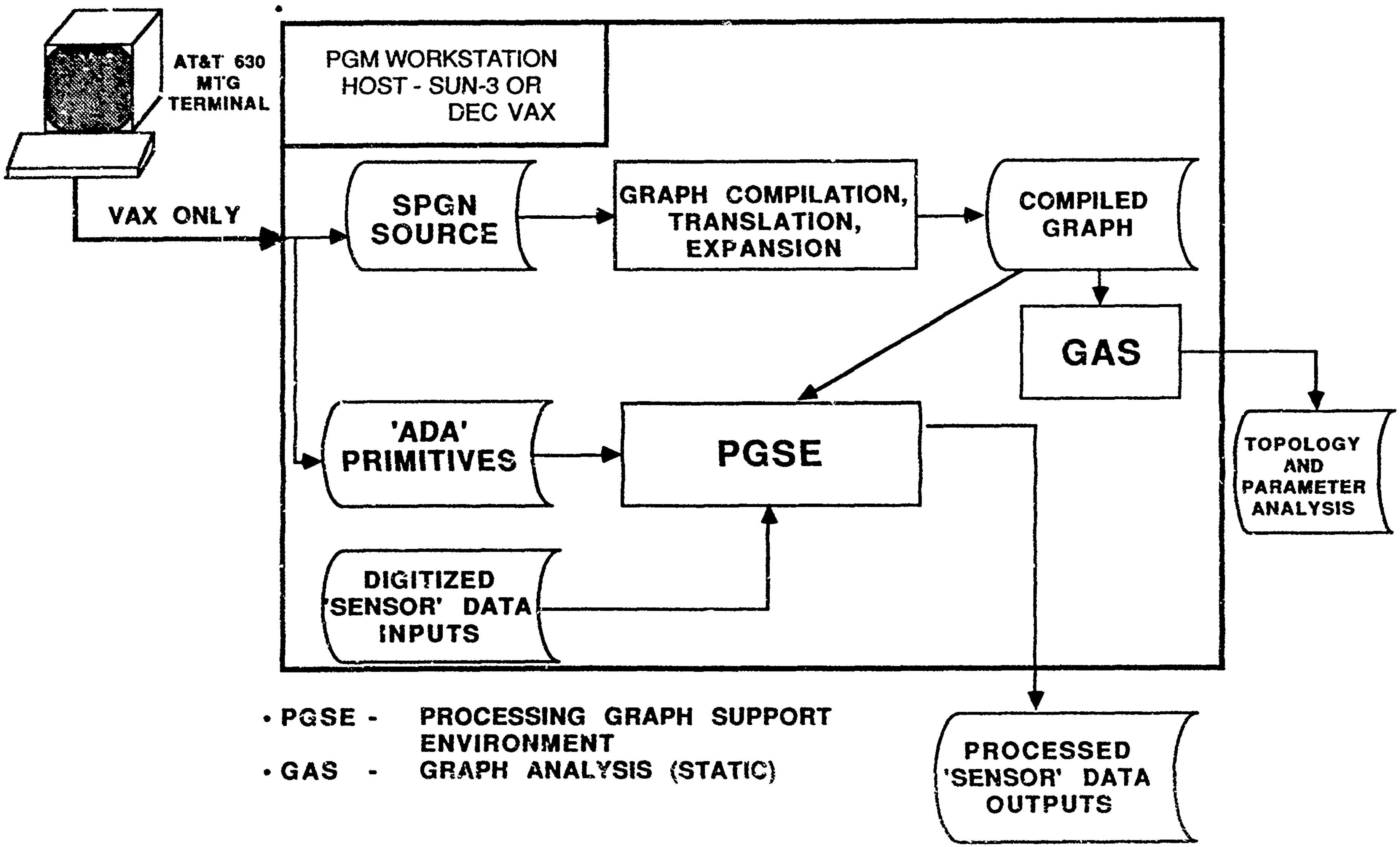
SIMULATION



- ETS - EVENT TIME SIMULATOR
- PID - PRIMITIVE INTERFACE DEFINITION

FIGURE 7.

EMULATION



- PGSE - PROCESSING GRAPH SUPPORT ENVIRONMENT
- GAS - GRAPH ANALYSIS (STATIC)

FIGURE 8.

SYSTEM GENERATION

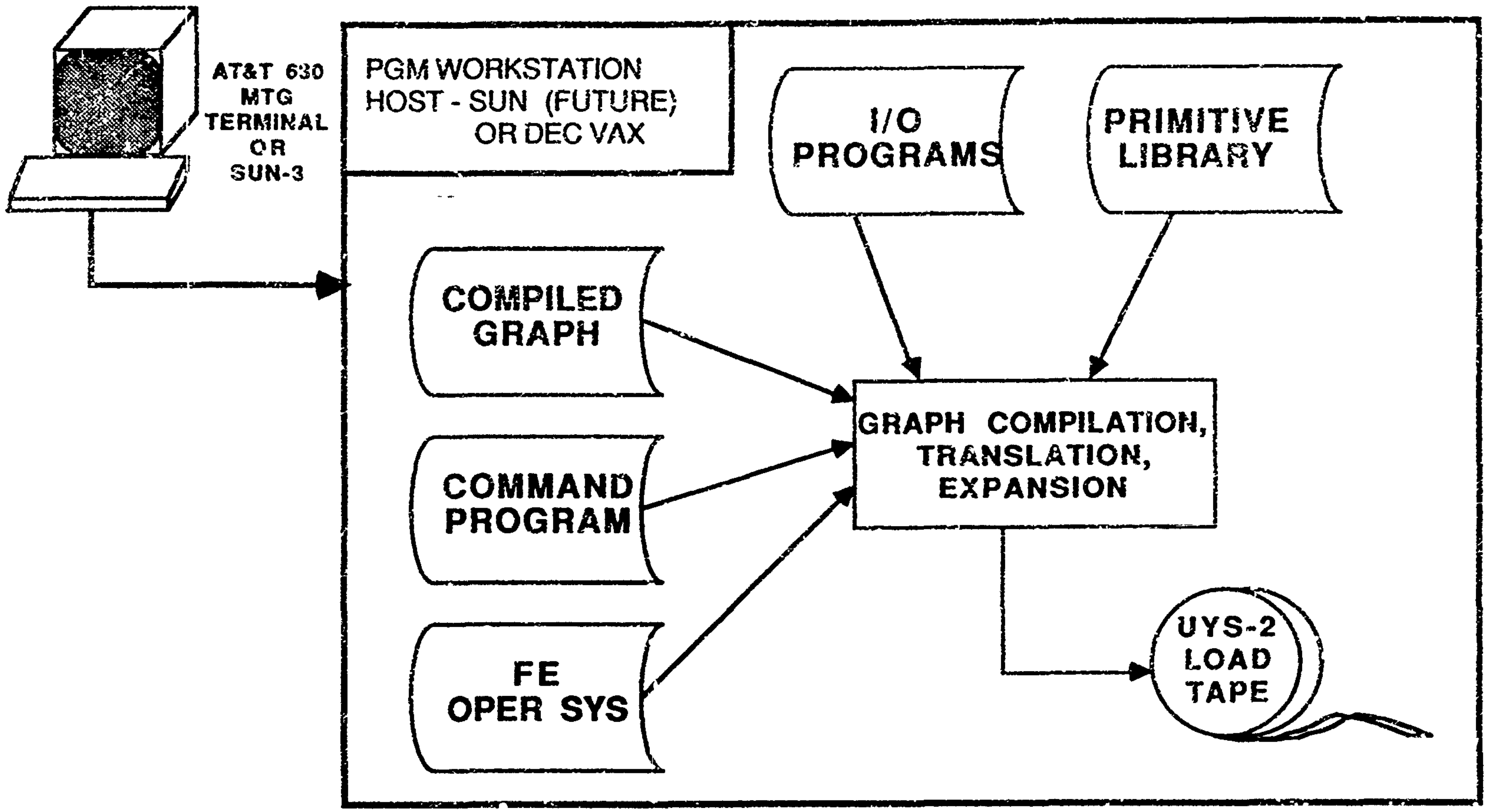
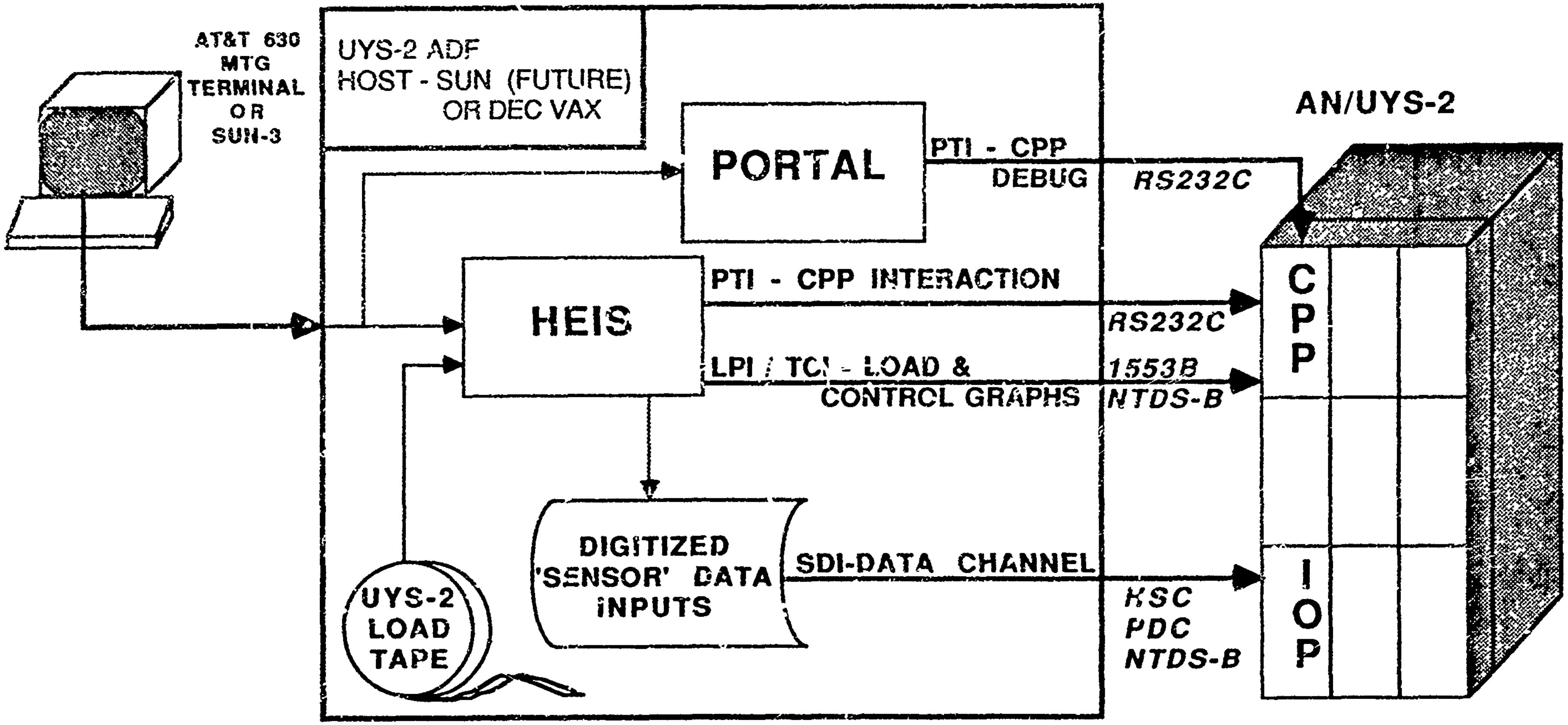


FIGURE 9.

DOWNLOAD, TEST & DEBUG



- LPI - LOAD PORT INTERFACE
- TCI - TACTICAL CONTROL INTERFACE
- PTI - PRODUCT TEST INTERFACE
- SDI - SENSOR DATA INTERFACE
- CPP - COMMAND PROGRAM PROCESSOR
- IOP - INPUT / OUTPUT PROCESSOR

FIGURE 10.

SURFACE SHIP SILENCING

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Abstract

Why silence surface ships? The need for acoustic silencing of submarines is widely understood. This is not always the case for surface ships. This paper examines the need for silencing surface battle group ships, describes the types of noise detectable/identifiable in ship signatures, lists the mechanisms which contribute to this noise, explains how noise problems are diagnosed, and finally describes ways to correct these problems.

There are four main reasons to design quiet battle groups. They are: (1) to reduce counterdetection, (2) to reduce counterclassification, (3) to reduce sonar self-noise, and (4) to reduce mutual interference within the battle group.

There are numerous major systems in a surface ship for which noise control features are design issues. These systems are noise sources which cause noise to be radiated through the hull into the water, and show up in the ship's acoustic signature. Surface ships go through acoustic trials to identify noise sources that make a ship easy to detect and classify. Several silencing techniques have been developed to correct problem sources once they have been diagnosed.

The goal is to quiet the entire battle group. Acoustic quieting aimed at getting every ship in the formation quiet is an essential step toward maintaining ASW superiority.

WHY SILENCE SURFACE SHIPS?

The need for acoustic silencing of submarines is widely understood. This is not always the case for surface ships. In an anti-submarine warfare, or ASW, combat environment where the threat submarine must rely on passive acoustic information only, a noisy surface ship can be dangerous to itself and to the entire battle group. Noise can greatly improve the enemy's detection and classification ranges, reduce ownship sonar performance, and inhibit a ship's ability to classify threat forces.

There are four main reasons to design quiet battle groups. The first is to reduce counterdetection, or to lower the probability of detection by threat forces by reducing the range at which detection will occur. The second is to reduce counterclassification, thereby increasing the difficulty with which the threat can identify individual targets within the battle group. The third reason is to reduce sonar self-noise, which will increase the performance capacity of own-force sensors. And the last is to reduce mutual interference, or to reduce the negative effect of noise within the battle group on ASW performance. (Another reason to quiet surface ships is to improve habitability. However, this aspect will not be addressed here.)

Figure (1) illustrates the benefits of surface ship silencing in the area of reducing counterdetection. In a typical ASW scenario, there are enemy forces (shown as SSN 1 and 2 in the figure) attempting to locate either the battle group or individual surface ships, such as the closest outer-screen escort, and friendly forces attempting to locate threat submarines. In the figure, the scenario is shown in the right-hand box. One carrier, two CG 47 class ships (one forward and one to the rear of the carrier), two FF 1052 class ships and an AOE can be seen being approached by two threat SSNs. The left-hand box gives relative ranges of detection, with and without friendly force quieting. In the top bar graph, the forward CG 47 is trying to detect SSN 1. With no battle group quieting, he can see him out to a certain range. His range is increased when all ships in the battle group have been quieted. Since he is forward of the noisy carrier and AOE, his improvement is not as striking as for the rear CG 47; as in the second bar graph, who is listening through the noisy high-value units. Below those, we see

the affect of silencing on the SSN's ability to detect the forward CG 47 and the carrier. As can be seen, large increases in the range at which friendly ships can detect threat submarines are anticipated, as well as large decreases in threat detection ranges, when quieting is implemented for the friendly forces.

Figure (2) shows the benefits of surface ship silencing in the area of reducing counterclassification. After detection is achieved, but before an enemy can confidently approach and attack, he needs confident classification information. Detection can be based upon broadband noise, i.e., acoustic energy across a wide band of acoustic interest, or it can be based upon narrowband detection, i.e., energy concentrated in a narrow band of acoustic interest. The more narrowband information available to an enemy, the more confident his classification capability. While it might be reasonable to speculate that classification would ordinarily not be dependent on obtaining broadband information only, the total amount of information required is certainly dependent on numerous strategies and/or tactical factors. Nonetheless, it can be seen that denying acoustic information makes counterclassification more difficult.

To date, there have not been significant surface ship acoustic quieting efforts for non-ASW capable surface ships, either due to resource limitations or because the impact that noisy ships have on the overall ASW performance of the battle group has not been clearly understood. Noisy units interfere with ASW defense of the battle group from enemy submarines. Figure (3) illustrates the degradation of ASW sonar coverage when a noisy ship is close to the ASW escort. The most severe degradation comes from those ships which have not received acoustic silencing treatments.

Improvement in ASW sensor performance can be achieved by reducing the amount of own ship noise heard by the sonar systems. The submarine, often "lying in wait" or traveling at low speed, has a substantial sonar self-noise advantage over the ASW capable surface ship which usually must escort at higher speeds. Ocean environments which are favorable for sound transmission only accentuate this advantage. Figure (4) illustrates this, where A is the baseline ship sonar self-noise, and B is the ship's sonar selfnoise after quieting. Surface ship acoustic quieting must focus on reducing the components of sonar self-noise which tend to provide the advantage to the submarine threat.

In addition to the above discussions, the changing world order and the rapid progress being made in the area of electronics both point to an increased need for surface force quieting. With the continued, unavoidable submarine technology transfer around the world, more countries will have the knowledge necessary to build "very quiet" non-nuclear submarines. Increased numbers of these vessels should be anticipated. Developments in electronics has provided the basis for improved, cheap underwater sensors. This progress has been accompanied by an improved knowledge of the ocean environment, as well as improved acoustic prediction techniques to take advantage of both the improved hardware and knowledge bases. All of this helps to answer the question, "Why silence surface ships?".

WHAT CAUSES NOISE IN SHIP SIGNATURES?

Figure (5) is an illustration of noise sources on a surface ship. Table (1) is a list of the major systems in a surface ship for which noise control features are design issues. In addition to these acoustic design issues, once built, a surface ship has numerous noise sources. These include aircraft, aircraft handling equipment, air driven tools, bearings, belts, blowers, cables, catapults and arresting gear, chains, compressors, conveyors, coupling guards, doors, elevators, engines, exhausts, fans, forklift trucks, gears, hatches, ladders, linkages, machine safety screens, motors, nozzles, personnel, pipes, plates, pneumatic tubes, pulleys, pumps, rollers, suction devices and valves. All of these potential noise sources combine to create the ship's acoustic signature.

Each ship has its own unique acoustic signature. A signature is a graphical summation of the noise made by the ship that radiates into the water. A ship's signature can be seen on a graph of signal level versus frequency. The signal level is expressed in decibels, or dBs. A decibel is a unit of intensity of sound used to show the difference between two sound pressure levels, or noise sources. A decibel, abbreviated dB, is a ratio of two pressures, the source being measured and a standard reference pressure. Let's look at a simple example of a ship signature, shown in Figures (6). Ship signatures vary with ship speed, machinery line-up, ship operations, and other factors. Therefore, a signature plot is for one specific set of conditions.

As can be seen in the sample signature, noise is both broadband, or continuous frequency, and narrowband, or discrete frequencies, called tonals. Tonals are caused by distinct, identifiable noise sources, such as the vibration caused by the rotational frequency of a piece of machinery. Narrowband analysis identifies tonals that can characterize the class, and even the specific hull, which generate them.

Noise travels from a source, through a propagation medium, to a receiver. Noise is a compressive wave caused by vibrational excitation of a solid, liquid or gas. In terms of detection range, a 6 dB reduction in a noise

source reduces the range at which that source can be detected by approximately half.

Ship noise falls into three categories: radiated noise, sonar self-noise, and airborne noise. All three of these are undesirable. Radiated noise is the noise caused by the ship that enters the water. Noise that is radiated into the water can travel a long distance, allowing detection and classification of the ship by threat forces, increasing the ship's vulnerability to mines, and also interfering with the performance of own-ship and battle group sonars (hull mounted sonars and towed arrays). Among the sources of radiated noise are propeller and propulsion machinery, auxiliary machinery, and flow noise, or the noise caused by the ship's movement through the water. Typically, at low speed, machinery noise dominates the signature, but at higher speeds, propeller and flow noise become increasingly important. Sonar self-noise is the noise made by the ship that is detected by the ship's own sonars. This noise interferences with the sonar performance, reducing the range at which threat forces can be detected. Sonar self-noise is caused by auxiliary machinery, flow, propeller and propulsion machinery, and bubble entrapment under the hull. Airborne noise can degrade the performance of shipboard personnel by making communication difficult and by affecting them physiologically. The dominant sources of airborne noise are shipboard machinery and active sonars.

Of the types of ship noise described above, radiated noise is the type that causes a ship to be detected and classified. There are three major sources of radiated noise:

(1) Machinery Noise - caused by propulsion machinery (such as diesel engines, main motors, and gears) and auxiliary machinery (such as generators, pumps, and air-conditioning equipment).

(2) Propeller Noise - caused by propeller cavitation and vibration.

(3) Hydrodynamic Noise - caused by flow, resonant excitation of cavities, plates, and appendages, and cavitation at struts and appendages.

These three major classes of noise also apply for sonar selfnoise. These sources of noise each dominate the ship signature at different times. This is illustrated by Figure (7). At low speeds, the ship's sonar hears mainly the ambient noise of the surrounding sea. As speed increases, machinery noise will begin to dominate the low-frequency end of the spectrum, and propeller and hydrodynamic noise combine to dominate the high-frequency end of the spectrum. Let's look at these three sources of noise more closely.

MACHINERY NOISE

Machinery noise comes from the mechanical vibrations of propulsion and auxiliary machinery, or from the movement of fluid at high velocity or with sudden pressure drops. Common sources include: unbalance, misalignment, bearings, gears, friction, and air and fluid flow. This noise contains discrete frequency components caused by fundamental and harmonic frequencies related to the particular machine. Therefore, a machine's rotational or cycling frequency and its harmonics are often seen as tonals in the ship's signature. Machinery vibrations originating inside the ship can excite vibrations in adjacent fluids, air or structures. Figure (8) illustrates how machinery noise can become airborne, structureborne or fluidborne, and then travels through the hull into the water.

PROPELLER NOISE

Propeller noise originates outside the hull due to the propeller rotation and the ship's movement through the water. The dominant source of propeller noise is cavitation, originating at the propeller blades and at the hub. As a propeller rotates in water, regions of low pressure are created at the tips and on the surfaces of the propeller blades. When these negative pressures become great enough, the water vaporizes, and cavities, or tiny bubbles, are formed. These bubbles then collapse, either in the turbulent stream or up against the propeller itself. Each bubble collapsing emits a sharp pulse of sound. This type of noise, caused by the creation and collapsing of bubbles or cavities formed by the action of the propeller, is called cavitation. Propeller cavitation can be broken down into two subsets, tip-vortex and blade-surface cavitation. In tip-vortex cavitation the bubbles are created at the tips of the propeller blades, and form the vortex stream which can be seen behind a rotating propeller as in Figure (9). In blade-surface cavitation, the bubbles are formed on the front or back surfaces of the propeller blades. Figure (9) also illustrates hub cavitation.

HYDRODYNAMIC NOISE

Water flowing past the hull produces turbulence which results in hydrodynamic noise, or flow noise, which is velocity dependent. As speed increases, turbulence increases, and results in increased flow noise. Any surface roughness or openings on the body cause additional turbulence, inducing more noise. Flow generated structural vibrations can also be created by the varying pressures of the turbulence and eddies in the passing water.

Flow of water past a surface ship hull produces radiated acoustic noise due to several hydrodynamic effects.

Cavitation on the hull or appendages occurs in areas of low pressure, similarly to the way propeller cavitation is produced, as discussed earlier. However, hull cavitation usually begins at a much higher speed than propeller cavitation. Therefore, hull cavitation, as well as cavitation around the sonar dome, does not show up significantly in the ship signature, but is a problem for sonar self-noise. In addition, water flow past appendages and struts can induce structural vibrations through vortex shedding off the trailing edge of the appendage or strut, called vortex streets. These vibrations result in radiated noise.

WHY IS NOISE MEASUREMENT NEEDED?

In a perfect noise model, sound is generated at a single source and is transmitted in a direct path. In this model it is easy to calculate how much sound will be heard at any distance from the source. In real situations, sound is generated at many sources, and transmitted by many paths, simultaneously. Figure (10) attempts to show some of the paths sound may take in a room, or in a compartment of a ship. Each noise problem is very complex. Applying the best theories and analysis will only give rough estimates.

A ship at sea has thousands of noise sources taking uncountable paths through the hull and then radiating via many paths in the sea to reach a listening enemy. Since theories and calculations will only give a rough estimate of the radiated noise it is necessary to actually measure radiated levels. By establishing accurate radiated noise measurement methods it is possible to determine detection ranges, identify and prioritize noise offenders, monitor noise reduction actions and provide tactical information. Radiated noise trials are a basic cornerstone upon which the NAVSEA Surface Ship Silencing Program operates.

METHODS OF SIGNATURE MEASUREMENT

Surface ships go through acoustic trials to diagnose noise problems which make them easier to detect and classify. Acoustics trials are conducted at several ranges. Ship signatures are measured and compared to class average data to identify class- or ship-peculiar tonals. Solutions to these noise problems are developed and implemented to make the individual ships, and therefore the battle force, less detectable and classifiable, as well as improve the performance of own-ship sonars.

Ship radiated noise is measured by running the ship past a stationary array of hydrophones that are at some distance from the ship in a low-ambient ocean environment. The ship passes the array on a straight-line course. Figure (11) shows the geometry of a typical radiated noise run. There are a number of noise measurement ranges that have fixed arrays installed on the ocean bottom, and there are several mobile sound boats that use arrays suspended over-the-side.

During radiated noise trials it is often customary to also measure self-noise using the ships sonar and to collect platform/structureborne noise at various locations on the ship. Trials are usually structured to meet the acoustic operating requirements of the ship and can last a few hours or several days. The most common trial is a twelve hour Surface Ship Radiated Noise Measurement, or SSRNM, trial which is conducted several months before deployment.

SSRMN trials typically identify high noise levels and then recommend corrective action to reduce the noise to normal class levels prior to deployment. Some examples of corrective action are cleaning fouled propellers, replacing a damaged propeller, repairing/adjusting the air systems, repairing bearings in a noisy pump, correcting a machinery imbalance, replacing ineffective sound mounts, or removing sound shorts. Even if the noisy item cannot be corrected, the problem is now known and can be used by the ASW forces to their best tactical advantage.

Longer acoustic trials, lasting several days, are typically conducted on the first ship of a new class of ships, or after a major modification/overhaul period, or to evaluate surface ship silencing R&D products. These trials establish baseline signature levels, and identify the specific noise items that control the signature and are most detectable. A quiet machinery line-up is often developed. Specific acoustic specifications can be verified, and any particular noise item can be evaluated. In addition to the underway runs past the array, several day trials include a dead-in-the-water period where noise is measured as various equipment are turned on and off. Data from these trials is used to identify and prioritize items requiring quieting, and to establish a noise benchmark against which future improvements can be measured.

HOW DO WE REDUCE SHIP SIGNATURE NOISE?

Noise control includes both source quieting, or stopping the source of the noise, and transmission path interruption, or keeping the noise from traveling to the water. Noise control measures for source quieting include purchasing quiet equipment, designing low rpm and quiet propulsors, using air systems, and ensuring hull fairness. Noise control measures that result in transmission path

interruption include air systems, absorptive and transmission loss treatments, resilient isolation of components, flexible hoses & couplings, acoustic enclosures and double wall construction, damping of foundations and structures, and sonar baffles.

Even though we incorporate quieting techniques into ship designs, if they are not properly maintained, the benefits may not be seen. For example, mounting a piece of equipment on resilient mounts will do no good if a tool gets jammed between the mount and the equipment for whatever reason. For reasons such as this, a Navy Training Plan for Surface Ship Noise Awareness has been approved, and formal classroom training is now taught.

HOW DOES SHIP SILENCING BENEFIT THE ENTIRE BATTLE GROUP?

The acoustic quieting of surface ships has been pursued on a ship specific basis for decades. Prime examples include DD 963 and CG 47 Class ships, and the DDG 51 Class design, as well as acoustic surveilance ships and special mission, such as mine warfare, ships. Backfit projects have also been pursued for ASW capable ships. However, numerous other US Navy surface ships, such as carriers, amphibious force assets, combat logistics support ships or battleships, have received little attention in the areas of surface ship acoustic quieting.

A battle force is ordinarily composed of both noisy high value units and quieter ASW capable escorts. These groupings yield complex total battle force noise fields, which work for an enemy and against ASW capable assets attempting ASW to protect the high value units. Pursuing silencing techniques on individual ship classes is not the total solution to the problem of attaining and maintaining ASW advantage. Operationally the top level signature of significance is the battle force signature, whether it be a multicarrier battle group, a convoy escort, or any combination of ships organized to support accomplishment of a mission role. The top level signature is not only a potential source of battle force detection, but also a prime information source for post-detection activity related to classification, approach and attack.

In the earlier Figures, we've seen how noise impacts the battle group in the areas of counterdetection, counterclassification, mutual interference, and sonar self-noise. In order to succeed in ASW in the future, acoustic improvement in surface ships has to proceed at a substantial rate. After analysis of how battle groups perform and conduct ASW, the NAVSEA Ship Silencing Office has recommended that silencing be added to ships of all existing types and sizes to improve their survivability. The objective is to make it as difficult as possible for an attacking submarine to detect, classify and target ships within the battle group. Acoustic quieting aimed at getting every ship in the formation quiet is an essential step toward this goal.

Table 1

Acoustic Design Issues

Air conditioning plant
Bleed air
Cooling water system
Distilling plant
Drainage system
Fresh water service system
Fuel oil and transfer system
Fuel oil service system
Gas turbine combustion air/exhaust system
Heating, Ventilation and Cooling system
High pressure compressed air system
Hull form characteristics
Lube oil service system
Power generation system
Propeller/propulsor
Propulsion system
Refrigeration system
Sanitary and sewage treatment system
Seawater service system
Ship service compressed air system
Sonar dome
Stabilizers
Steam heating system
Steering system

References

[1] MacDonald, S., "Silent Ships Sink Subs", Surface Warfare, May/June 1988.

[2] Trott, W.G., "Introductory Noise Control", Acoustic Design Engineering Department 443, General Dynamics, 1986.

[3] Urick, R.J., "Principles of Underwater Sound", 3rd ed., New York: McGraw-Hill Book Company, 1983.

[4] Burdic, W.S., "Underwater Acoustic System Analysis", New Jersey: Prentice-Hall Inc., 1984.

[5] Ross, D., "Mechanics of Underwater Noise", New York: Pergamon Press, 1976.

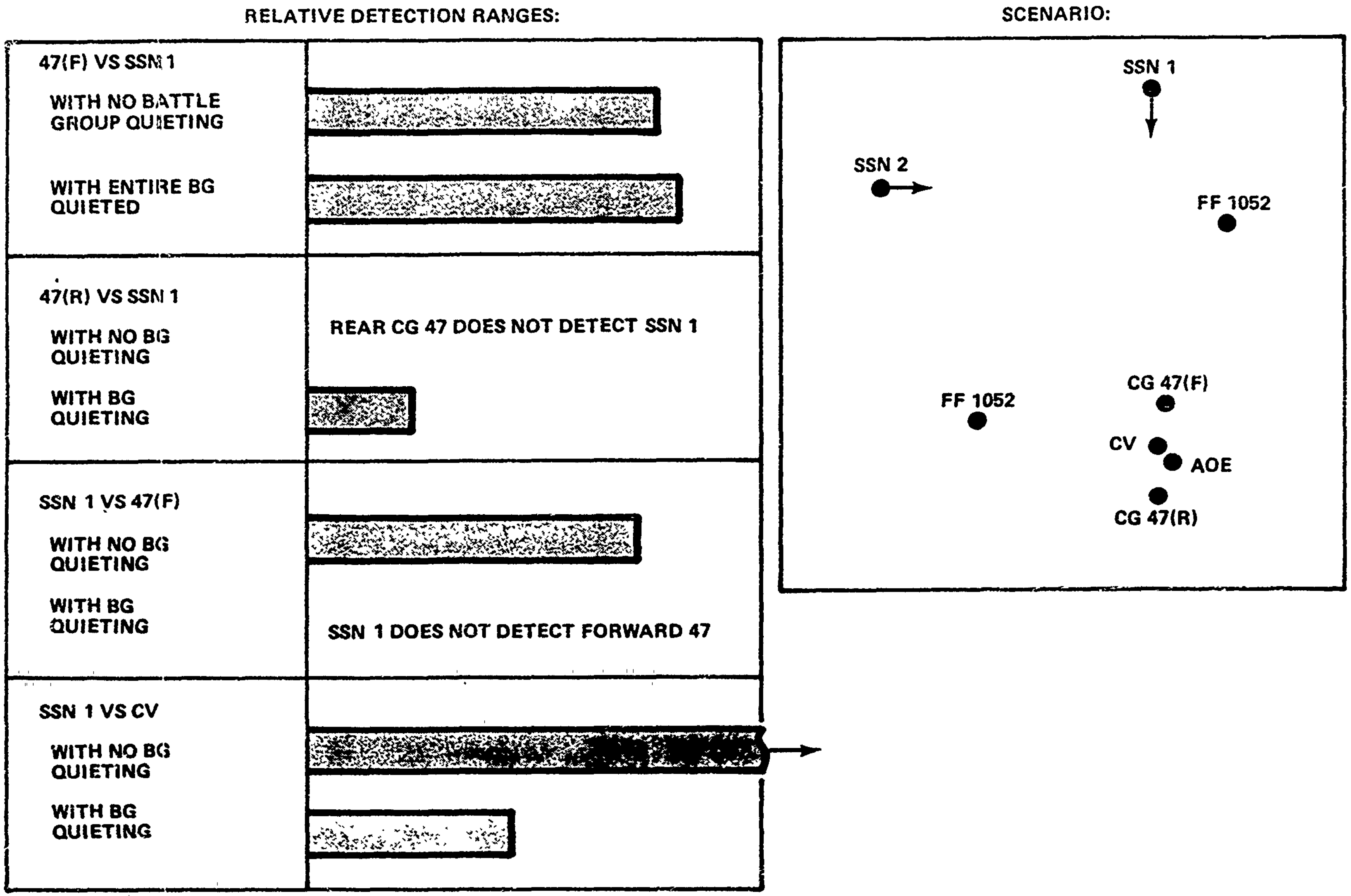


FIGURE 1. DETECTION IMPROVEMENTS FROM SURFACE SHIP SILENCING

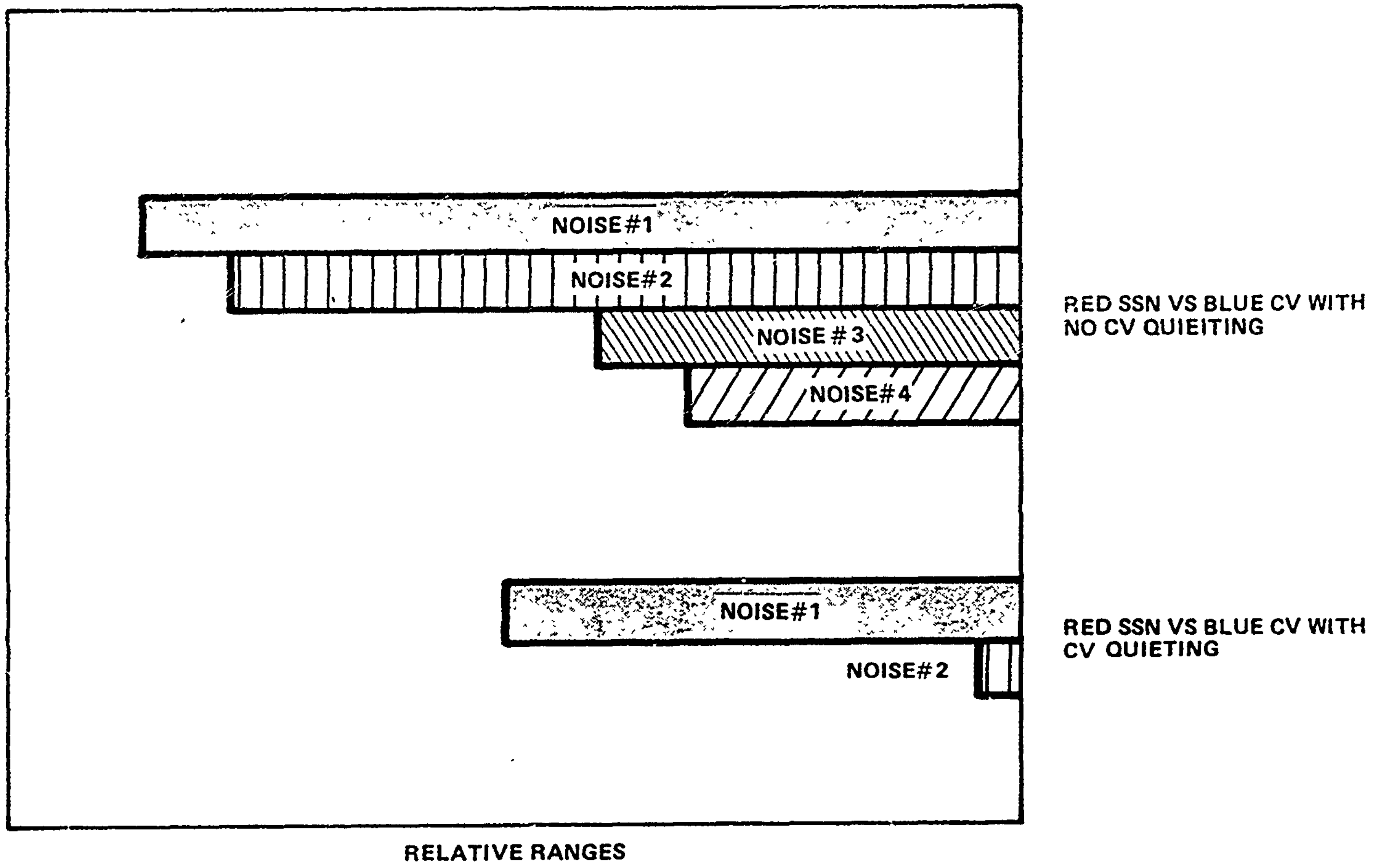


FIGURE 2. CLASSIFICATION IMPROVEMENTS FROM SURFACE SHIP SILENCING

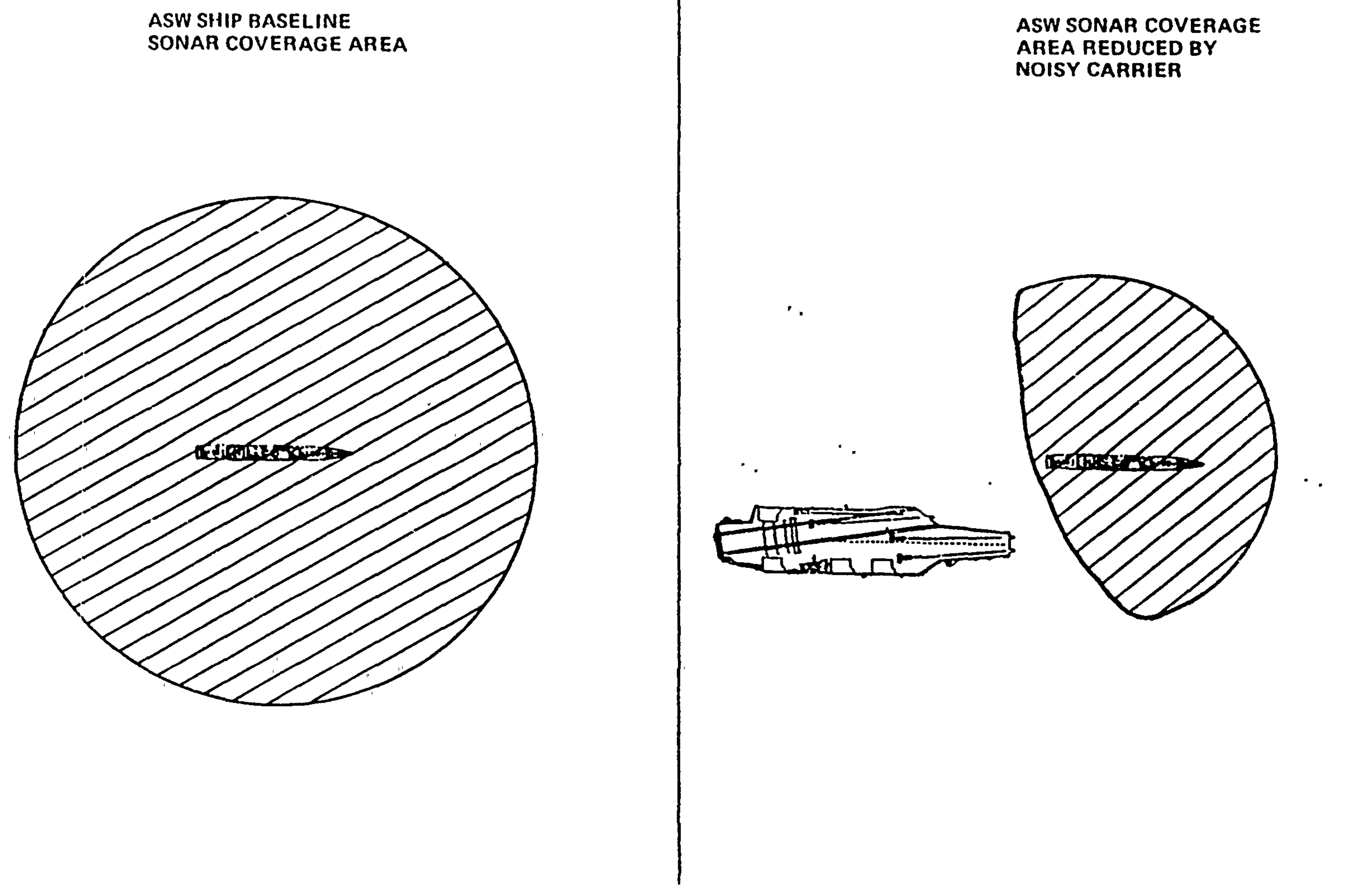


FIGURE 3. MUTUAL INTERFERENCE IMPACT ON DETECTION RANGES

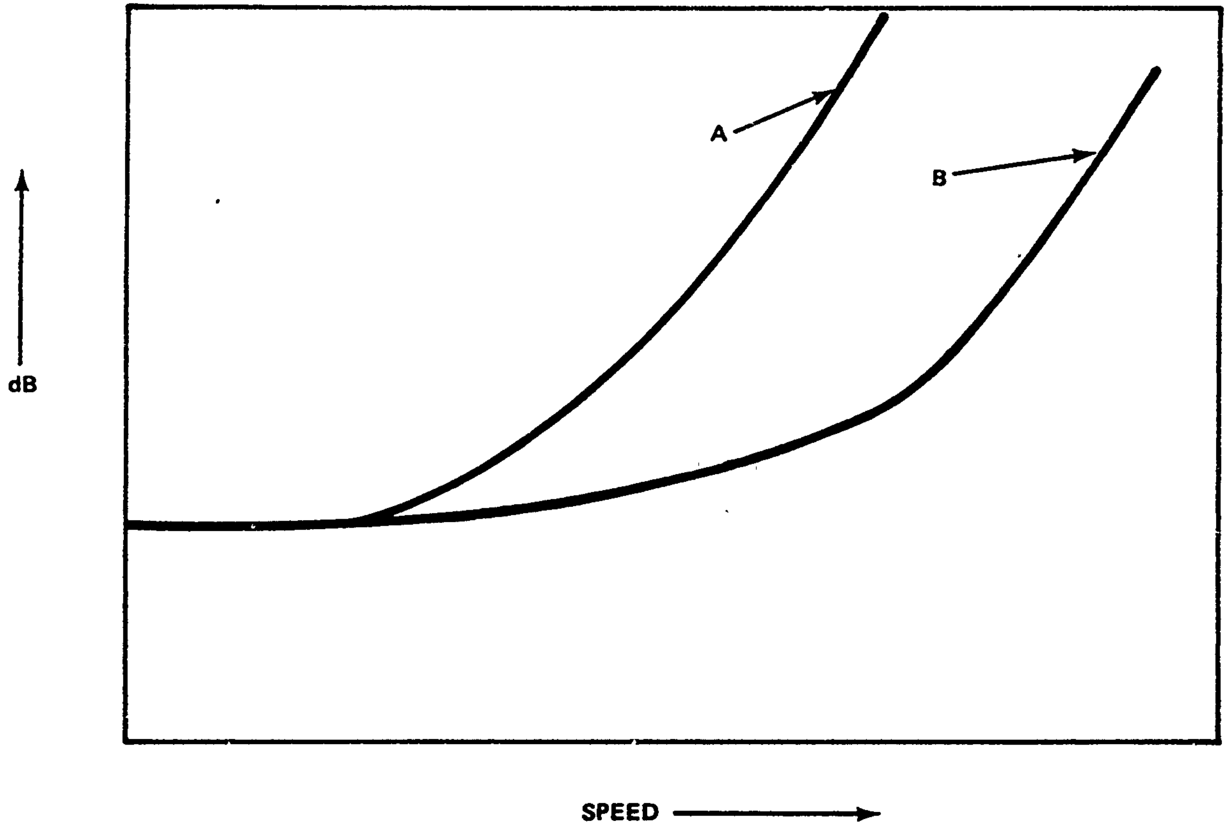


FIGURE 4. PLATFORM NOISE SPEED DEPENDENCE

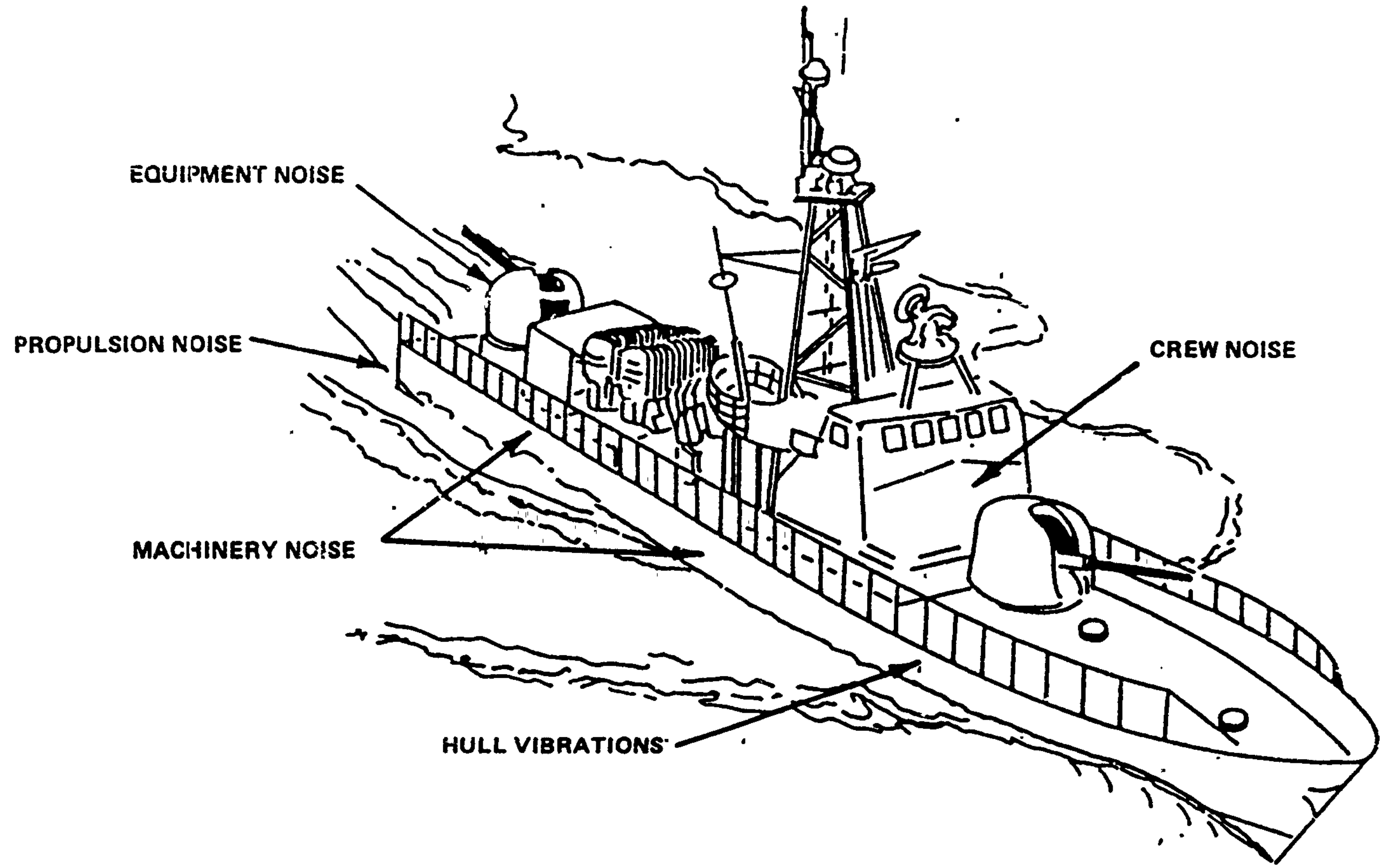


FIGURE 5. SHIP GENERATED NOISE

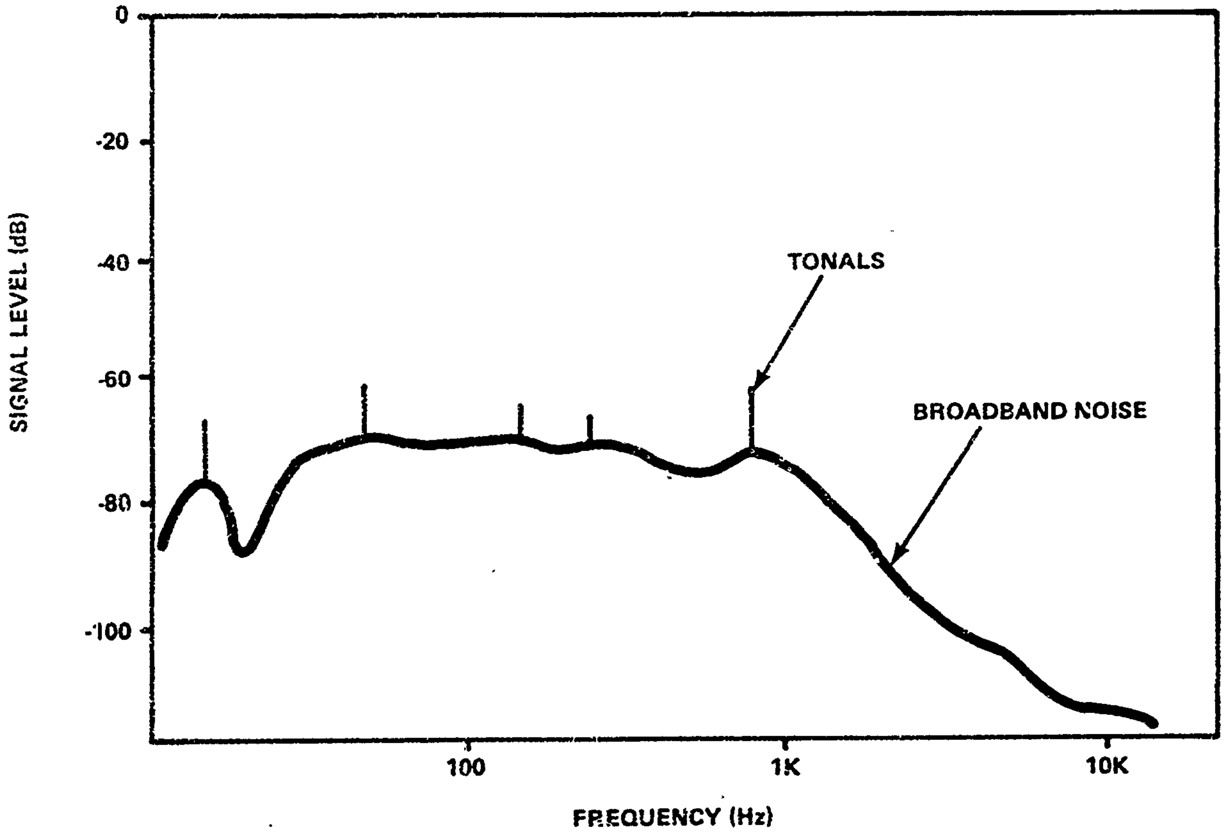


FIGURE 6. EXAMPLE NOISE SIGNATURE

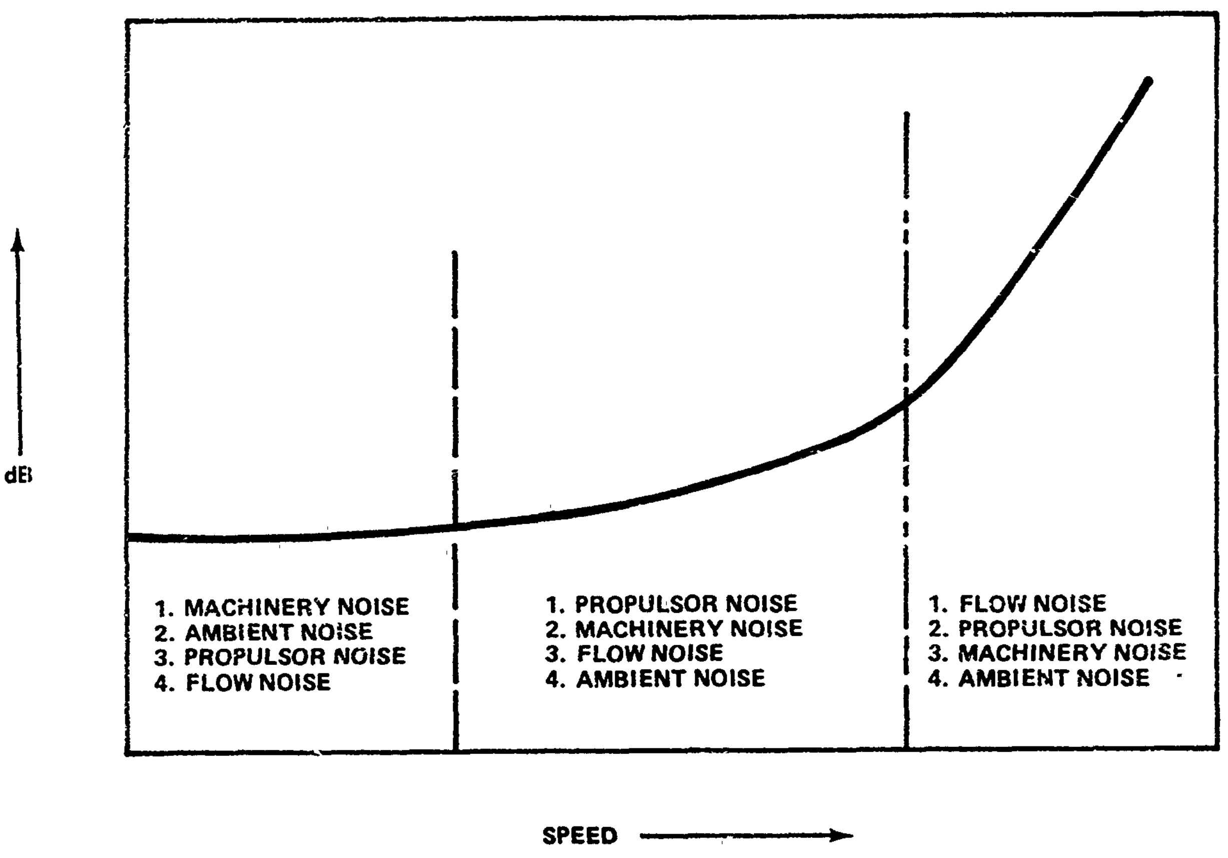


FIGURE 7. TYPICAL SELF-NOISE SOURCES VS SPEED

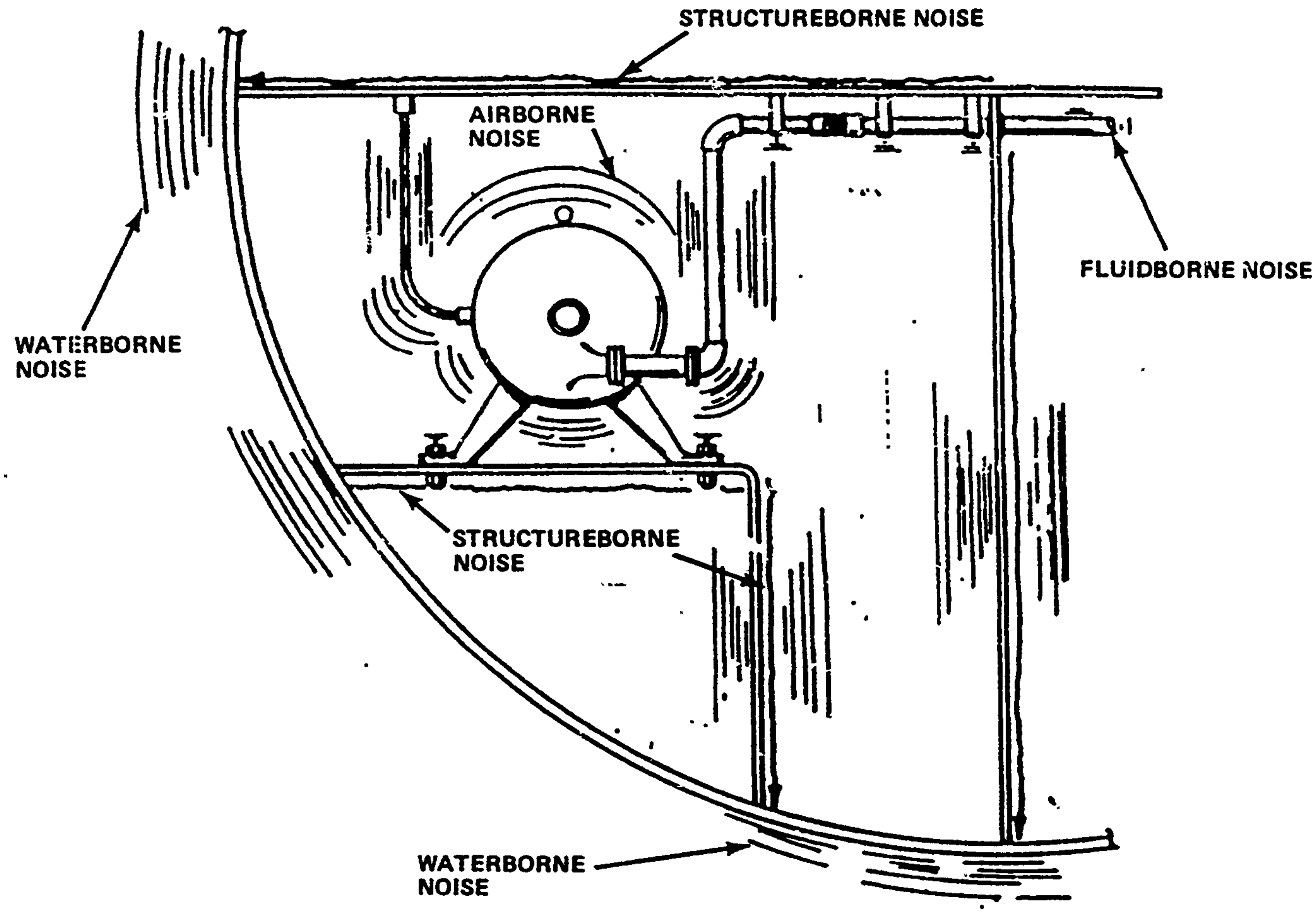


FIGURE 8. NOISE PATHS

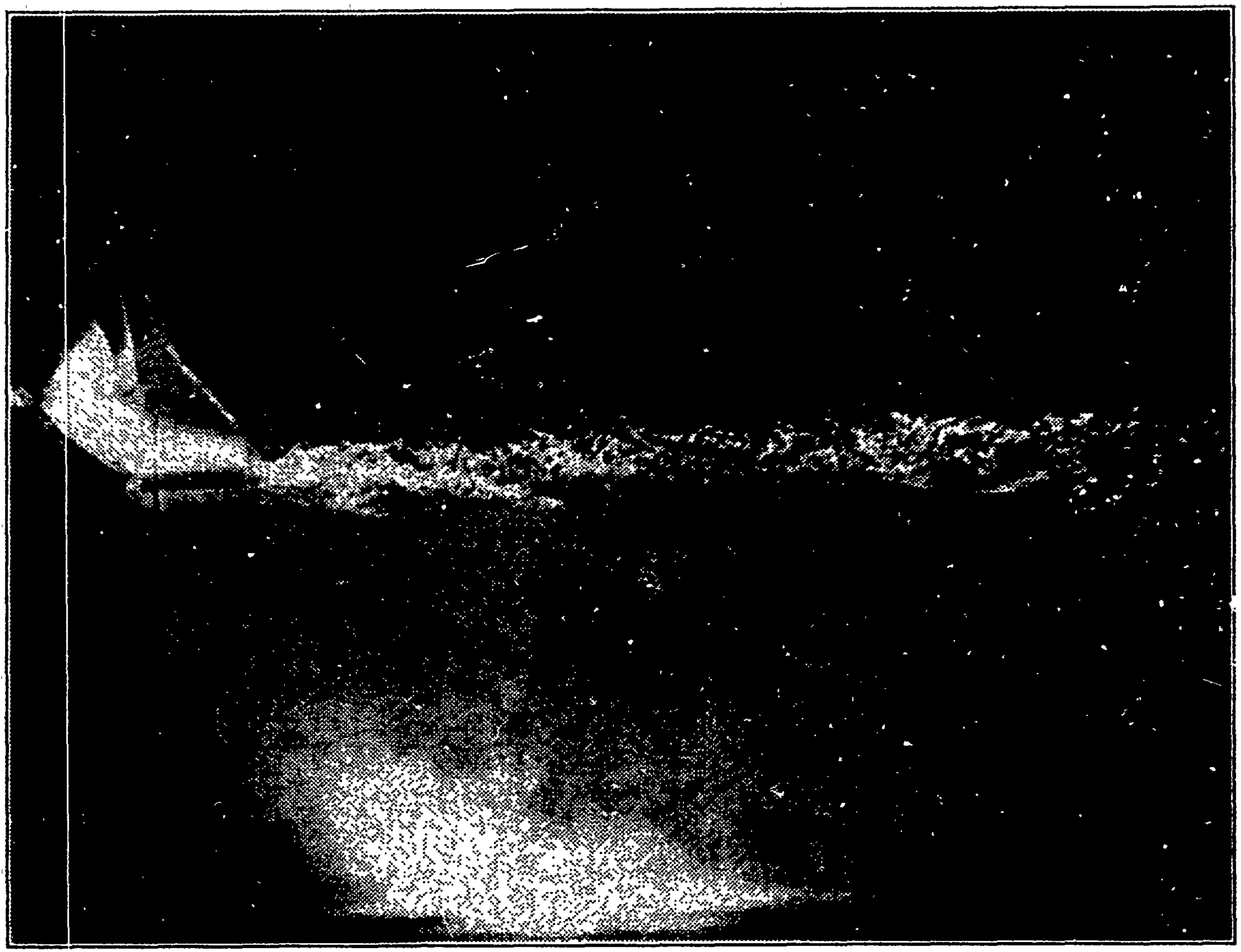


Figure 9. Propeller / Hub Cavitation (Photographs taken in Garfield Thomas Water Tunnel at Pennsylvania State University)

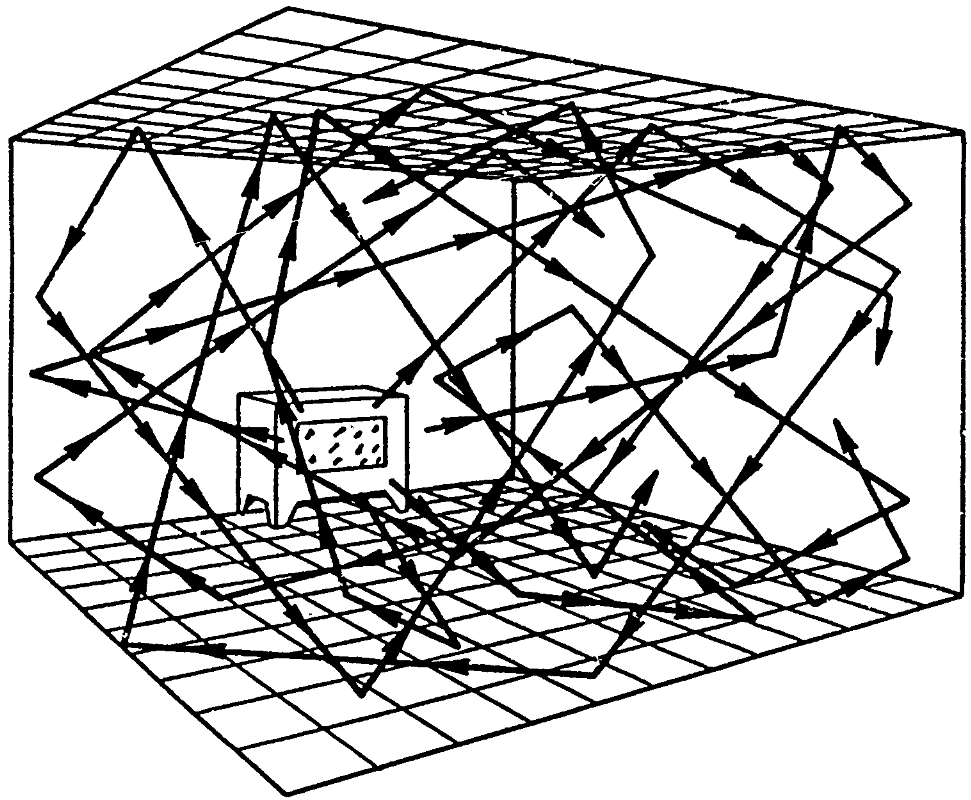


FIGURE 10. DIFFUSE SOUND FIELD IN A COMPARTMENT

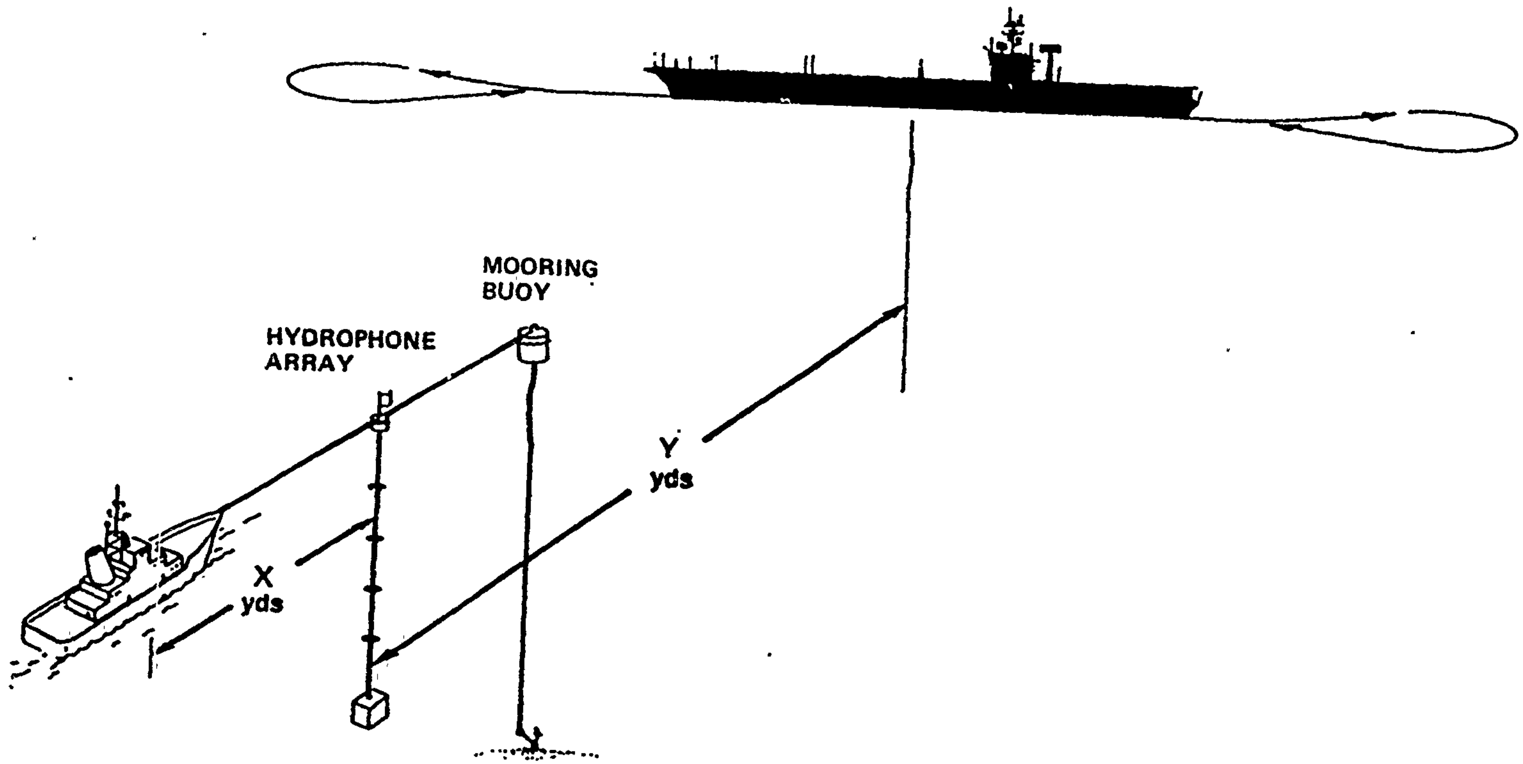
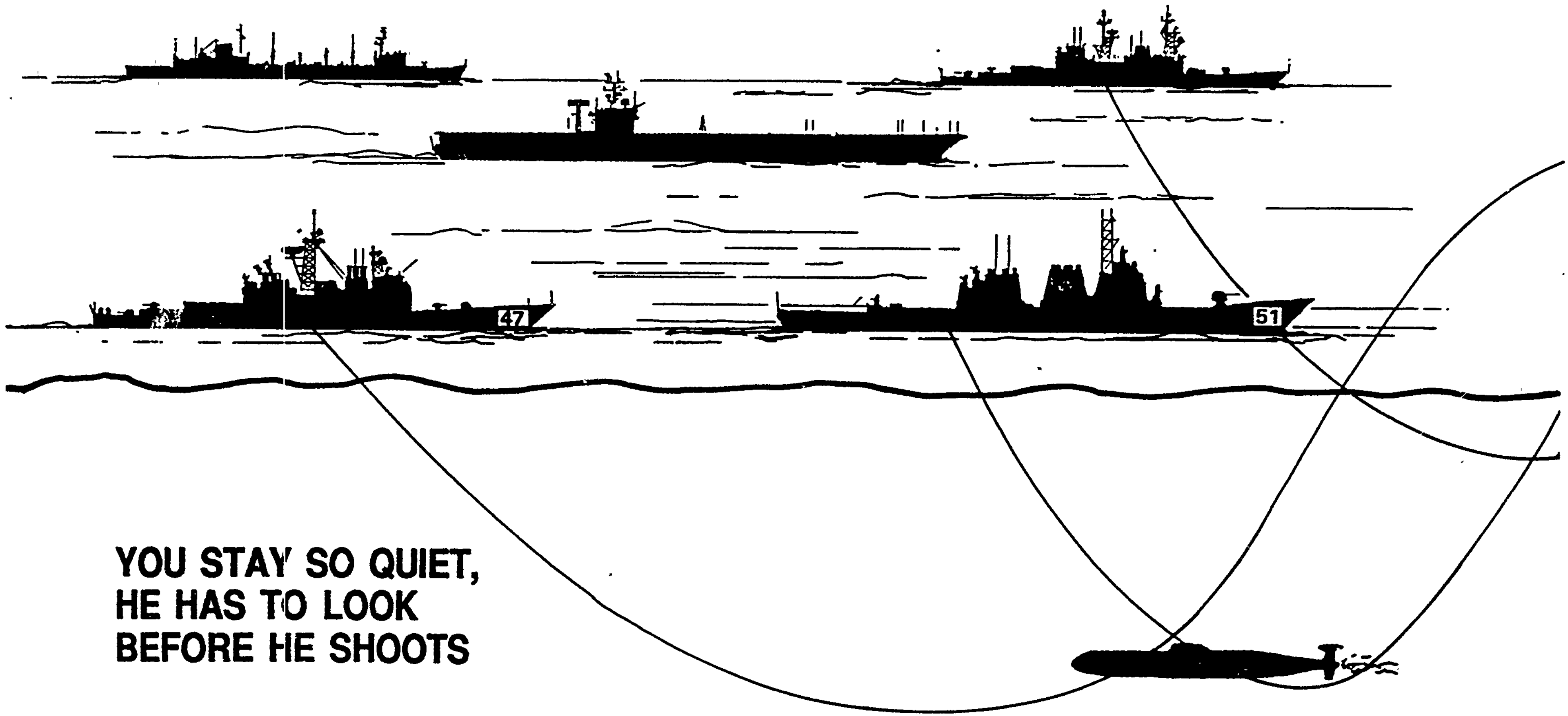


FIGURE 11. ACOUSTIC TRIAL GEOMETRY

SILENCE WINS . . . . . *if*



**YOU STAY SO QUIET,
HE HAS TO LOOK
BEFORE HE SHOOTS**

A Navy Perspective On Insensitive Munitions

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April, 1990

Approved For Public Release
Distribution Unlimited

The views expressed herein represent the Joint Service Requirements for Insensitive Munitions. These requirements will be applicable to all Departments and Agencies of the Department of Defense.

ABSTRACT

The Navy's efforts to make munitions insensitive to unplanned stimuli is known throughout the ordnance community and coordinated with other services through the Joint Ordnance Commanders Group (JOCG) and with industry and NATO allies.

Standardization test procedures, data requirements, and assessment methods are called out in MIL-STD-2105(A), Draft, dated 19 January 1990, "Hazard Assessment Tests for Non-Nuclear Munitions". This revised document incorporated the U.S. Military Service comments only. This is one milestone that has near and long term impact on weapon and ship design, and safety/vulnerability testing.

Other areas on IM program execution include industry's research and development efforts, projected NATO conventional munition requirements, Congressional defense funding, and in-house technical expertise. These areas of influence should periodically be jointly reviewed by the ship design and combat system program offices.

DEFINITIONS

Explosive. An explosive is a solid or liquid substance (or a mixture of substances) which is in itself capable, by chemical reaction of producing gas at such temperature, pressure and speed, of causing damage to the surroundings. Included are pyrotechnic substances even when they do not evolve gases. The term explosive includes all solid and liquid materials variously known as high explosives, propellants, together with igniter, primer, initiation and pyrotechnic (e.g.,illuminant, smoke, delay, decoy flare and incendiary) compositions.

All-up round. Refers to the completely assembled munition as intended for delivery to a target or configured to accomplish its intended mission. This term is identical to the term all-up weapon.

Exudation. A discharge or seepage of material. The material may be either a component of a chemical payload or a component of an explosive/propellant payload.

Detonation Reaction (Type I). The most violent type of explosive event. A supersonic decomposition reaction propagates through the energetic material to produce an intense shock in the surrounding medium (e.g., air or water) and very rapid plastic deformation of metallic cases, followed by extensive fragmentation. All energetic material will be consumed. The effects will include large ground craters for munitions on or close to the ground, holing/plastic flow damage/fragmentation of adjacent metal plates, and blast overpressure damage to nearby structures.

Partial Detonation Reaction (Type II). The second most violent type of explosive event. Some, but not all of the energetic material reacts as in a detonation. An intense shock is formed; some of the case is broken into small fragments; a ground crater can be produced, adjacent metal plates can be damaged as in a detonation, and there will be blast overpressure damage to nearby structures. A partial detonation can also produce large case fragments as in a violent pressure rupture (brittle fracture). The amount of damage, relative to a full detonation, depends on the portion of material that detonates.

Explosion Reaction (Type III). The third most violent type of explosive event. Ignition and rapid burning of the confined energetic material builds up high local pressures leading to violent pressure rupturing of the confining structure. Metal cases are fragmented (brittle fracture) into large pieces that are often thrown long distances. Unreacted and/or burning energetic material is also thrown about. Fire and smoke hazards will exist. Air shocks are produced that can cause damage to nearby structures. The blast and high velocity fragments can

cause minor ground craters and damage (break-up, tearing, gouging) to adjacent metal plates. Blast pressures are lower than that of a detonation reaction.

Deflagration Reaction (Type IV). The fourth most violent type of explosive event. Ignition and burning of the confined energetic materials leads to nonviolent pressure release as a result of a low strength case or venting through case closures (leading port/fuze wells, etc.). The case might rupture but does not fragment; closure covers might be expelled, and unburned or burning energetic material might be thrown about and spread the fire. Pressure venting can propel an unsecured test item, causing an additional hazard. No blast or significant fragmentation damage to the surroundings; only heat and smoke damage from the burning energetic material.

Burning (Type V). The least violent type of explosive event. The energetic material ignites and burns, non-propulsively. The case may open, melt or weaken sufficiently to rupture nonviolently, allowing mild release of combustion gases. Debris stays mainly within the area of the fire. This debris is not expected to cause fatal wounds to personnel or be a hazardous fragment beyond 50 feet.

Propulsion (Type VI). A reaction whereby adequate force is produced to impart flight to the test item in its least restrained configuration as determined by the life cycle analysis.

Service review organization. The organization within the DOA, DOAF or DON which assess the explosives safety and IM characteristics of weapon systems and makes recommendations to the appropriate approval authority.

Weapon system. A munition and those components required for its operation and support.

Munition. An assembled ordnance item that contains explosive material(s) and is configured to accomplish its intended mission.

Munition subsystem. An element of an explosive system that contains explosive material(s) and that, in itself, may constitute a system.

Explosive device. An item that contains explosive material(s) and is configured to provide quantities of gas, heat, or light by a rapid chemical reaction initiated by an energy source usually electrical or mechanical in nature.

Hazardous fragment. For personnel, a hazardous fragment is a piece of the reacting weapon having an impact energy of 58 ft-lb (79 joules) or greater.

Sympathetic detonation. The detonation of munition or an explosive charge induced by the detonation of another like munition or explosive charge.

Bare round or configuration. A munition with no external protection or shielding from the environment such as container, barrier or shield.

Threat hazard assessment. An evaluation of the munition life cycle environmental profile to determine the threats and hazards to which the munition may be exposed. The assessment includes threats posed by friendly munitions, enemy munitions, accidents, handling, etc. The assessment shall be based on analytical or empirical data to the extent possible.

INTRODUCTION

The revised MIL-STD-2105A (Navy), Draft, dated 19 January 1990 provides the basic mandatory tests and test requirements to be conducted for the assessment of safety and insensitive munitions characteristics for all non-nuclear weapon systems and munitions, munition systems and explosive devices. After results of the basic mandatory tests are analyzed, supplemental tests in accordance with MIL-STD-882 can be performed if required. The MIL-STD-2105A (Navy), Draft, applies to all non-nuclear munitions (i.e., all-up missiles, rocket, pyrotechnics), munitions subsystems (e.g., warheads, fuzes, propulsion units, safe and arm devices, pyrotechnic devices, chemical payloads), and other explosive devices. Nuclear systems will be excluded.

The revision to MIL-STD-2105A (Navy) lists the passing criteria for all the basic tests. Results will be reviewed by the appropriate service review organization for compliance with safety, operational and insensitive munitions requirements. The lead service will have the responsibility for implementing these requirements.

GENERAL REQUIREMENTS

The program manager shall be responsible for planning and executing a hazard assessment test program which includes a test plan based on a realistic life cycle environmental profile. The program manager shall ensure that the conducted test program uses the minimum of test units required in MIL-STD-2105A (Navy), Figure 1, to complete the basic tests. Safety design goals for the test plan shall be established by the program manager and approved by the service review organization for review and concurrence.

A hazard assessment test program shall consist of a test plan which is based on the life cycle environmental profile used to perform the threat assessment. Guidance available in other documents such as MIL-STD-1670 for air-launched weapons shall be used to develop this profile which includes environmental conditions and limits munitions will encounter throughout the life cycle (i.e., temperature, humidity, and vibration). The service review organization shall review and concur with the environmental profile prior to conducting the tests.

The conditions that simulate or duplicate the hazards of credible normal, abnormal combat situation(s) identified by the threat assessment shall determine the safety and sensitivity characteristics. The test parameters shall be selected to reflect maximum stress levels forecast. Unless otherwise specified, all items shall be tested at 77 $\pm$ 18°F.

The program manager shall generate and submit a detailed test report, consistent with the test plan, to the service review organization. The test report shall include rationale for deviations from the test plan, the test item configuration and identification, test date, test results, and safety and vulnerability related conclusions.

The test item shall be production hardware or equivalent. The test plan shall indicate if the item is different from production hardware.

Test equipment/fixtures shall not interfere with the test stimulus imposed on the test item. Tolerances of the test conditions and instrumentation calibrations shall be in accordance with MIL-STD-810 unless otherwise specified.

The test item configuration shall be the same as the configuration of the item in the life cycle phase being duplicated by the test, and be specified in detail in the test plan and approved by the service review organization.

Prior to testing, the test item shall be inspected visually and radiographically to assure no existence of unusual conditions. All unit safety mechanisms and devices shall be set or otherwise adjusted to a safe condition. Photographs of the test setup including identification information in the field of view shall be taken.

The test item shall be inspected visually and radiographically after the test is completed to determine its structural integrity and to compare with the pre-test examination results. The following are requirement to be documented whenever the test item is destructed: a complete description of significant post-test remains of the munition (Figure 2), Post-Test Remains Map (Figure 3) and Post-Test Remains Tabulation (Figure 4).

DETAILED REQUIREMENTS

The basic safety tests consist of: 28-Day Temperature and Humidity (T&H); Vibration; 4-Day T&H; 40-Foot Drop; Fast Cook-off; Slow Cook-off; Bullet Impact; Fragment Impact; Sympathetic Detonation; Shaped Charge Jet Impact and Spall Impact. Results of each test shall be documented on the appropriate data sheet. The following is a brief description of these tests:

28-Day T&H Test

The test item is exposed to alternating 24-periods of high and low temperatures at fixed relative humidity levels specified in the environmental profile. The test procedures shall reflect the temperature and humidity conditions measured or forecast. Each test item shall be visually examined prior to testing and record the appropriate critical dimensions to determine the material condition. A minimum of three units shall be tested. The passing criteria listed below are based on the final observation:

1. No reaction of the explosive.

2. No exudation of the explosive.

3. Rocket motor propellant shall not crack or separate from case lining in a manner which would create a hazardous condition in handling or use.

4. All safety devices shall remain in the safe position.

5. The structural integrity of the itemshall not be compromised by corrosion, loosening of joints or other physical distortions.

Vibration Test

The test item is exposed to the most severe vibration environment that it normally encounter during the logistic cycle. The test shall be conducted along the appropriate mutually perpendicular axes, and may consist of one or a combination of the following: random vibration, vibration cycling and resonant dwell. Test procedures shall reflect vibration modes and temperatures anticipated in the item's environment. A minimum of three items which have undergone and passed the 28-day T&H test shall be tested. The passing criteria are the same as those listed under the 28-day T&H test.

4-Day T&H Test

This test is a version of the 28-day T&H test. All data relative to the 28-day T&H test are required for the 4-

day T&H test. A minimum of three items which have undergone and passed the 28-day T&H and Vibration tests shall be tested. The passing criteria are the same as those listed under the 28-day T&H test.

40-Foot Drop Test

This field test is designed to evaluate the safety response of the test item to the stress load associated with a free-falling impact onto a striking plate in various attitudes.

The test item is dropped from the lowest point of the item to the point of impact of 40 feet, complying with following orientations:

a. Longitudinal axis horizontal

b. Longitudinal axis vertical (aft-end down)

c. Longitudinal axis vertical (forward-end down)

The test consists of free-falling drops of the environmentally pre-conditioned items (Figure 1) in the bare configuration (one drop per item) onto the striking plate. Photographic or other instrumentation shall be utilized to verify the striking velocity. Still photographs shall be taken to record the condition of the test item and setup prior to and after the test. The passing criteria include the following:

1. No reaction of the explosives in the item

2. No rupture of the item resulting in exposed explosives

3. The item shall be safe to handle and be disposed by normal EOD procedures.

Fast Cook-Off Test

The test item is engulfed in the flame envelope of a liquid fuel fire and the reaction is recorded as a function of time. The item shall be tested in the configuration in the logistic phase being duplicated by the test. Items configured with rocket motors shall be restrained to avoid launching due to a propulsive reaction. The restraining and suspension method shall not interfere with the heating of the item. The test item shall be positioned so that its horizontal center line is 36 inches above the surface of the fuel or in the attitude most probable in the weapons life cycle environment. The test item shall not fall into and being quenched by the fuel. Four thermocouples with time constants of 0.1 second shall be located 4 to 8 inches outside the ordnance skin for each item tested. Thermocouple readings shall be recorded at least once every second until test completion. A minimum of two tests shall be conducted. Still photographs shall be used to record the condition of the test item and test site prior to and after the test. Video or motion picture sound photography shall be utilized to record the cook-off event. The test item shall have no reaction more severe than burning.

Slow Cook-Off Test

This test determines the reaction temperature and measures the overall response of major munition subsystems to a gradually increasing thermal environment at a rate of 6°F per hour until a reaction occurs. A minimum of two tests shall be conducted. Temperature recording device shall be utilized to record temperatures. Steel witness plates shall be positioned beneath the test item to provide evidence of the item reaction. Still photographs shall be used to record the condition of the test item and test site prior to and after the test. Video or motion picture sound photography shall be utilized to record the cook-off event. No reaction more severe than burning shall occur.

Bullet Impact Test

This test is conducted to determine the reaction of the test item when impacted by at least three 50 caliber armor-piercing (AP) bullets at 2800 $\pm$ 200 ft/sec. Figure 5 displays the test configuration. A minimum of two test items shall be tested. In the first test item the bullets impact the largest quantity of explosives. The bullets impact the most sensitive location in the second test item. The airblast overpressure of the test item is measured and steel witness plates are positioned beneath the test item to provide evidence of the test item reaction. High-speed motion picture cameras, electronic velocity screens, or equivalent, are used to measure the bullet impact velocity within $\pm$ 50 ft/sec. High-speed motion picture photography, motion picture sound photography or video shall be used to record the test item reaction. Still photographs of the test item shall be taken before and after the test. No reaction more severe than burning shall occur.

Fragment Impact Test

This test determines the response of the test item to the impact of a one-half inch, 250 grain, mild-steel cube traveling at 8300 $\pm$ 300 ft/sec. Figure 6 presents the sample test configuration. A minimum of two items shall be tested with a fragment impacting the largest quantity of explosives in one test item and a fragment impacting the sensitive location of the other test item. Steel witness plates positioned beneath the test item shall be used to provide evidence of the test item reaction. Speed motion picture cameras, electronic velocity screens, or equivalent, shall be used to measured the fragment impact velocity. The apparatus shall be ac-

curate to measure the fragment velocity within 300 ft/sec. High-speed motion picture photography, motion picture sound photography or video shall be used to record the test item reaction. Still photographs of the test item shall be taken prior to and after the test. The test shall have no reaction more severe than burning.

Sympathetic Detonation

This test evaluates the likelihood a detonation reaction may be propagated from one unit to another within a group or stack of munitions. Generally, one munition (donor) is adjacent to one or more like munitions (acceptors). The test setup should replicate the packaging conditions and stowage arrangement for the logistics life cycle phase deemed to pose the greatest threat of sympathetic detonation. The test setup shall incorporate one or more acceptors positioned (relative to the donor) at location(s) deemed most vulnerable to sympathetic detonation. Where appropriate, the test setup shall also incorporate simulated (or dummy) units to provide additional confinement of the donor and the acceptor(s) as illustrated in Figure 7. The donor may be initiated using an external stimulus that simulates initiation by the threat stimuli most likely to cause detonation of the test item as determined by the threat hazard assessment. Alternatively, if the test item is designed to detonate when functioned, the donor may be initiated using its normal booster system or a booster charge of similar power. For items that are not designed to detonate, the donor may be initiated axisymmetrically using a booster charge of sufficient size/output to ensure sustained, stable detonation of the explosive. The donor may be modified to accommodate the required booster provided the modifications are not expected to have a significant effect on the fragmentation or blast of the item. The test design shall incorporate either high-speed motion picture cameras to record the reaction(s) of the acceptor(s), or steel witness plates beneath the test items to provide rough indications of the shock pressure within each acceptor relative to the shock pressure within the donor. Transducers shall be placed along each of two mutually perpendicular axes illustrated in Figure 8. Baseline overpressure data shall be obtained by conducting a calibration test firing using either a single test item or an explosive charge of approximately the same yield as the donor test item. The setup for the calibration test shall be identical to the actual test setup with respect to test item mounting, transducer placement, and sensitivity and response of the measurement system. The test shall not have a detonation of any acceptor.

Shaped Charge Jet Impact Test

This test determines the reaction of the test item when impacted by the jet of a M42/M46 grenade, representative of a top attack or an 81-mm precision shaped charge (or both), representative of a hand-held HEAT attack. Figure 9 provides a schematic of a typical test configuration. The munition shall be tested in the transport/storage or operational use configurations or both. The 81-mm shaped charge shall be initiated in a manner that ensures proper formation of the shaped charge jet. A minimum of two test items shall be used. Steel witness plates shall be placed under and on two opposite sides of the test item as witnesses to the degree of reaction. High-speed motion picture photography, motion picture sound photography or video shall be used to record the test item reaction. No detonation shall occur as a result of the shaped charge jet impact.

Spall Impact Test

The response of munitions to impact hot spall fragments is determined in this test. The test setup is illustrated in Figure 10. The spall fragments are produced by impacting a 1-inch thick rolled homogeneous armor (RHA) plate with the shaped charge jet of an 81-mm precision shaped charge. The standoff distance between the shaped charge and the RHA plate shall be 5.8 inches. The placement of the test item behind the RHA plate shall be selected so that it is impacted by spall fragments only. A minimum of 4 spall fragments/10 in2 of presented area (up to 40 fragments) shall impact the test item. The test item configuration shall be a bare munition subsystem. Closed-circuit video, real time motion picture photography shall be used to document the test events. No sustained burning shall occur as a result of the spall impact test.

AREAS OF INFLUENCE

Each service approaches the implementation of IM philosophy differently. The Air Force is primarily concerned with base magazine storage of munitions; (survivability and quantity distance) they recognize the loss of an aircraft due to a catastrophic failure of an airborne munition. The Army's primary concern is combat vehicle survivability and munitions transport. The Navy's concern is ship survivability (consider the carrier USS Forrestal fire of 1967). Each service's operational environment provides a basis for evaluation of IM requirements, testing, and approval or waiver of a munition.

Industry involvement in IM programs is driven by profit and patriotism. Their interest lies in the understanding of the operational performance required for the munitions they would manufacture and test as a result of the competitive contracting process. The government can influence the industrial technology base through evaluation of industry's research and development efforts, and by providing the private sector with the feedback and

direction of Navy in-house IM technology, and the challenges of technology, as well as the lessons learned. Cooperative effort between industry and government is essential if affordable, functioning insensitive munitions are to be fielded in a constrained acquisition cycle. Industry would be willing to commit their capital resources to facilities and research depending on the long-term commitment of the government, but this is fiscally driven by Congressional defense funding.

The formal partnership between program offices is defined within OPNAVINST 8010.13B of 27 June 1989. The Office of Primary Responsibility (OPR), usually the weapons program manager for each Navy munition, submits an annual Plan of Action and Milestones (POA&M) to the IM office for review by an IM Coordination Group.

The POA&Ms display funding IM requirements, which include all research and development, product improvement, and procurement. A cooperative effort between industry and government can ensure a long-term Congressional defense funding commitment.

A request for IM certification is accompanied by a system description, list of test results, and technical assessment by the IM office. The combat systems community addresses ship survivability alternatives for less sensitive energetic materials, new munition design concepts, and ordnance container hardening. The other ship survivability alternatives of ship magazine hardening, weapon launcher hardening, and upgraded damage control fire fighting are addressed by the ship design community.

The Navy policy on approval or waiver of a munition is considered in all transactions with other services or foreign military agencies. It is recognized that if a foreign weapon technology passes the scrutiny of equivalent United States testing, it has a high probability for acceptance within the NATO community. The NATO AC 310 group has an oversight for Allied Ordnance Publication 7 (AOP-7), "Manual and Description of Tests Used for the Qualification of Explosive Materials for Military Use".

With the situation in Eastern Europe, the munitions technology required for the twenty-first century and the appropriate cooperative technology community, is dependent on one's area of influence and perspective.

REFERENCES

Government documents. Unless otherwise specified, the following standards form a part of this document to the extent specified herein.

STANDARDS

MIL-STD-331 Fuze and Fuze Components,

Environmental and Performance Tests for

MIL-STD-453 Inspection, Radiographic

MIL-STD-810 Environmental Test Methods and Engineering Guidelines

MIL-STD-1670 Environmental Criteria and

Guidelines for Air-Launched Weapons

FIGURES

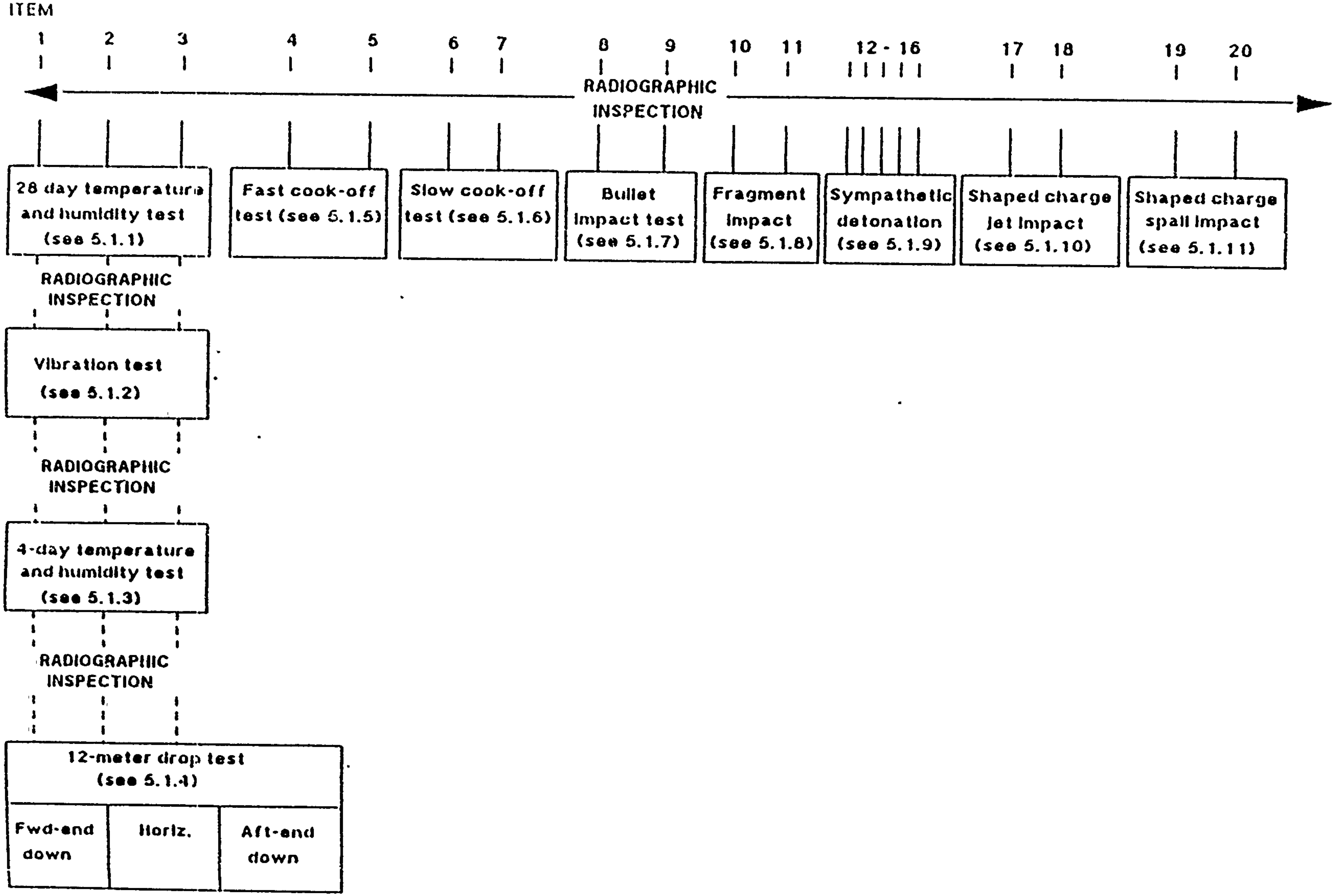


FIGURE 1
ITEM NUMBER AND TEST SEQUENCE

SAMPLE

POST-TEST REMAINS MAP
DATA SHEET

Item Tested: ______________________________

Lot # ______________ S/N ______________

Ambient Conditions: ______________________________

Test Facility: ______________ Date: ______________

Test Item Description: ______________________________

Fragment Projector Description: ______________________________

Test Setup (attach sketch): ______________________________

____

Test Results

Narrative Description: ______________________________

____

Explosive reaction level: ______________

Post Test Description

Number and location of impact fragments: ______________ Impact Velocity: ____

* Airblast overpressure ______ psi at ______ ft, time to peak ______ msec

______ psi at ______ ft, time to peak ______ msec

______ psi at ______ ft, time to peak ______ msec

* Airblast overpressure data shall be supplied if there is an explosive reaction.

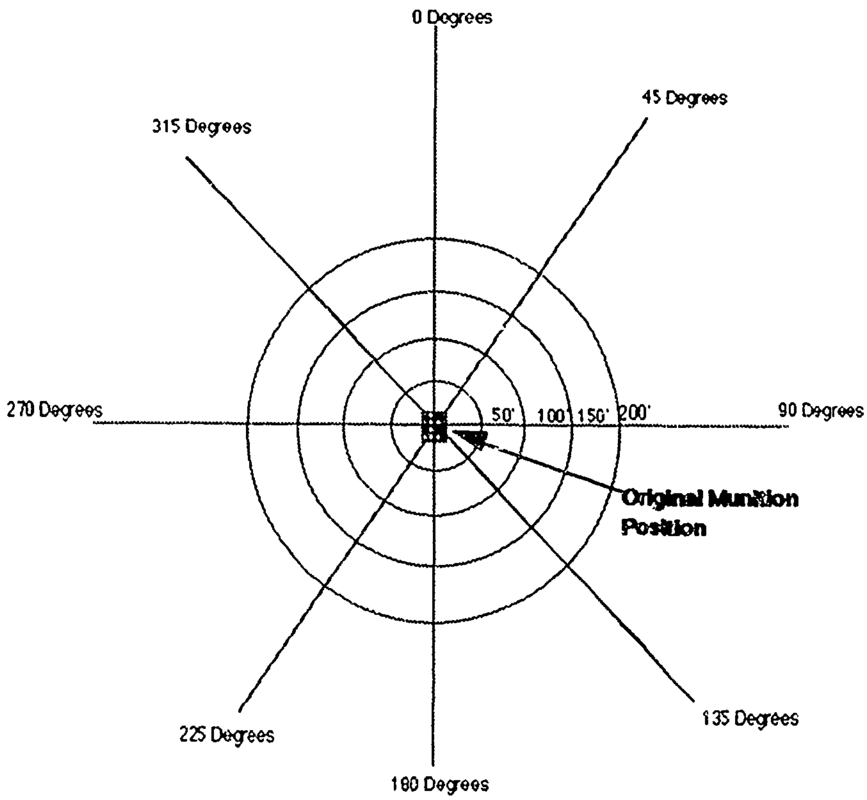
Witness Plate Description: ______________________________

Test Engineer: ______________

Signature: ______________

FIGURE 2. Fragment impact test data sheet

SAMPLE
POST-TEST REMAINS MAP



NOTE: Identify shotline and test item orientation

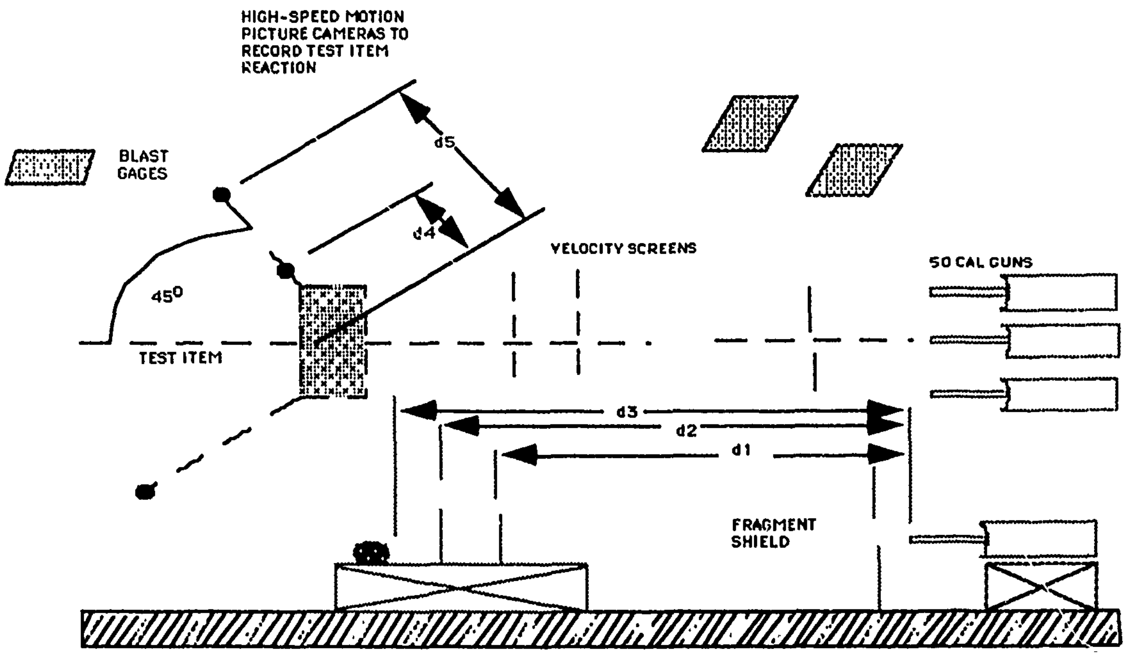
FIGURE 3. Post-test remains map.

SAMPLE

POST-TEST REMAINS TABULATION

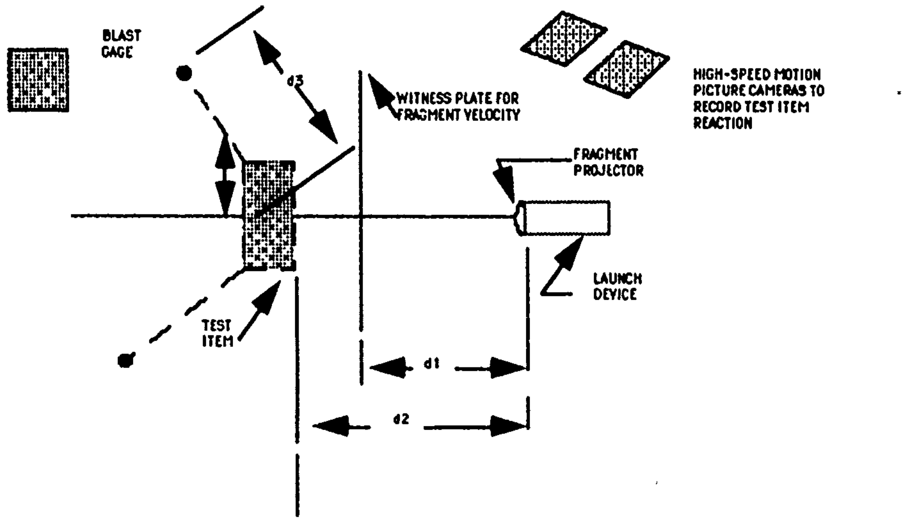
DISTANCE	WEIGHT	ANGLE	DESCRIPTION

FIGURE 4. Post-test remains tabulation.



NOTES d1 = DISTANCE TO FIRST VELOCITY SCREEN
d2 = DISTANCE TO SECOND VELOCITY SCREEN
d3 = DISTANCE TO TEST ITEM
d4 = DISTANCE TO FIRST BLAST GAGE
d5 = DISTANCE TO SECOND BLAST GAGE(S)

FIGURE 5. "Typical" bullet impact test configuration



d1 = DISTANCE FROM FRAGMENT MAT TO WITNESS PLATE
d2 = DISTANCE FROM FRAGMENT MAT TO TEST ITEM
d3 = DISTANCE FROM TEST ITEM TO BLAST GAGE(S)

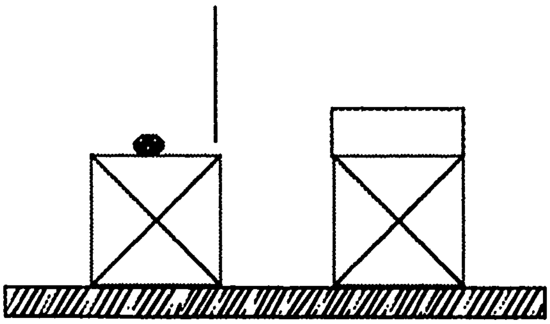
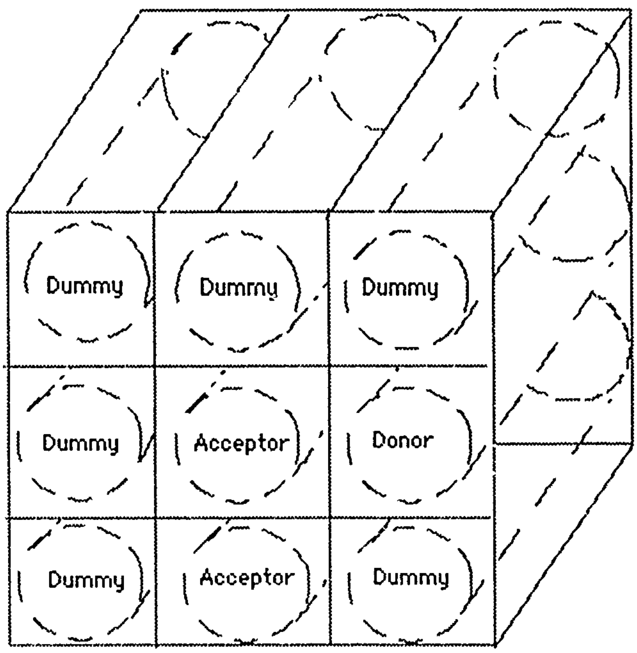
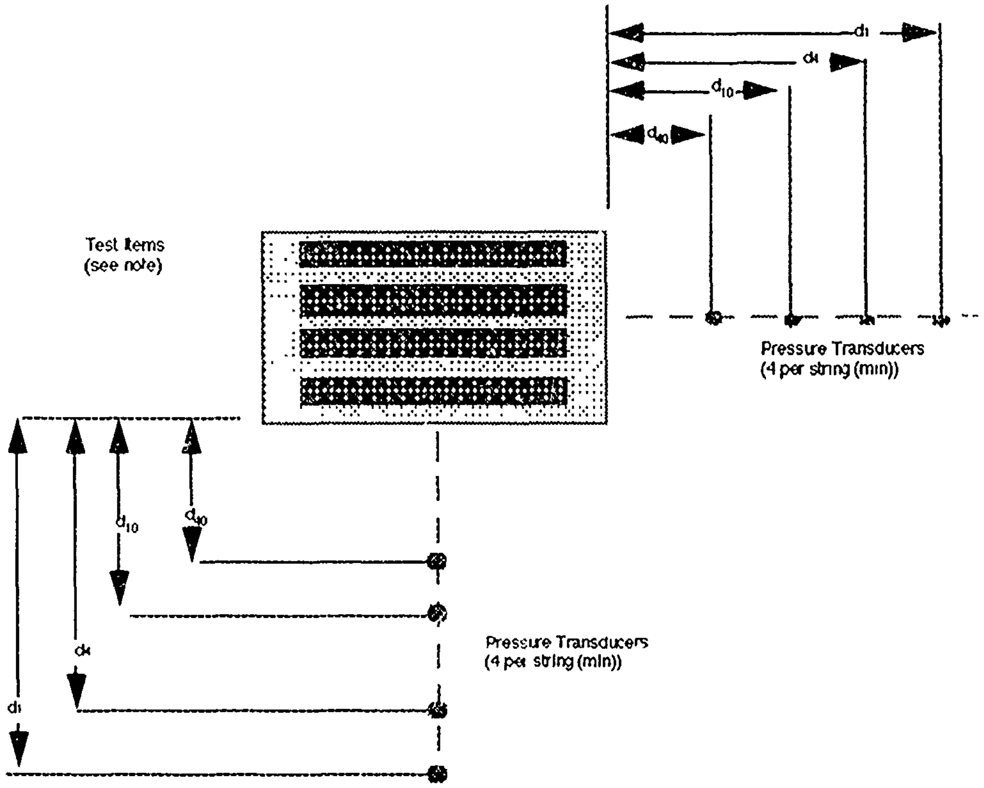


FIGURE 6. "Typical" fragment impact test setup.



NOTE. For illustrative purposes only, packaging, arrangement of test items, and number and placement of acceptors shall be determined based upon the threat hazard assessment.

FIGURE 7. Sample arrangement of test items for sympathetic detonation test.



d40 = Distance at which peak airblast overpressure is expected to be approximately 40 psig if all test items detonate.

d10 = Distance at which peak airblast overpressure is expected to be approximately 10 psig if all test items detonate.

d4 = Distance ar which peak airblast over pressure is expected to be approximately 4 psig if all test items detonate.

d1 = Distance at which peak airblast over pressure is expected to be approximately 1 psig if all test items detonate.

Figure 8. Sample placement of pressure transducers for sympathetic detonation test (plan view).

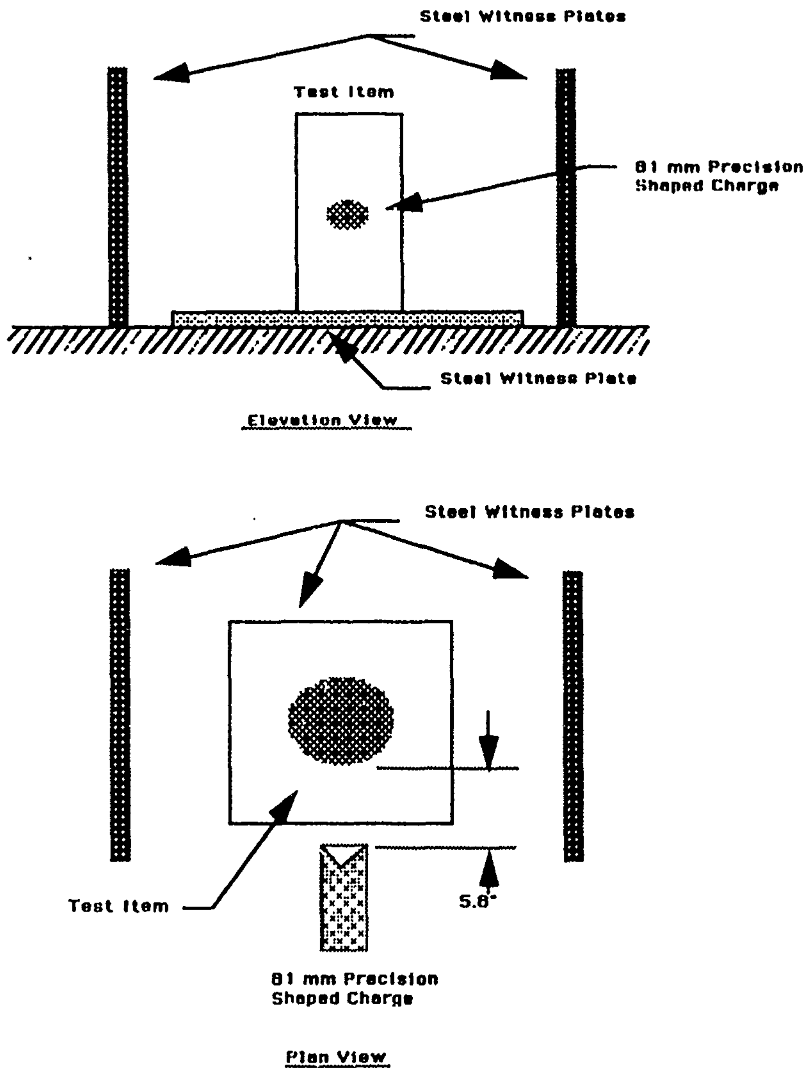


FIGURE 9. "Typical" shaped charge impact test configuration.

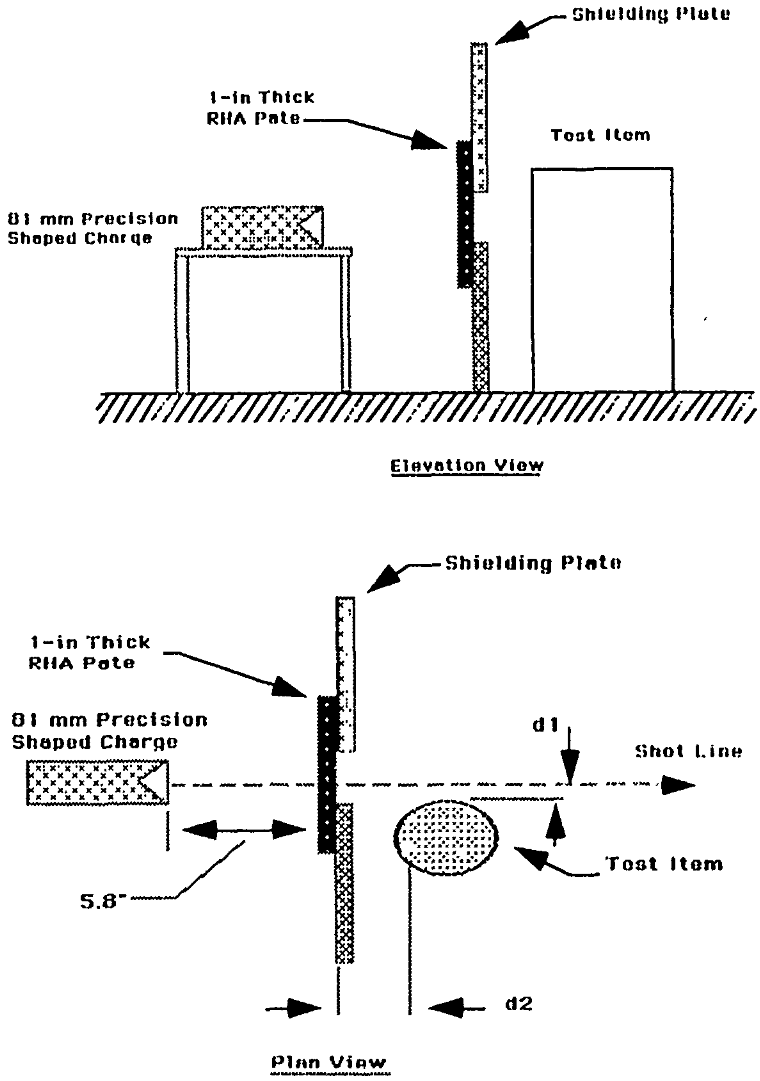


FIGURE 10. "TYPICAL" SPALL IMPACT TEST CONFIGURATION

THE NAVY'S ROLE IN SATELLITE-BASED TRANSPORTATION TRACKING

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Abstract

The movement of munitions and other hazardous material is the focus of increased attention by government and the private sector. New and more stringent requirements are being established to ensure the safe and secure transport of these materials. One of the keys to this improved control is knowing the location and status of each of these shipments while in transit.

Since June 1986, NAVSEA has managed the Naval Ordnance Transportation Tracking System (NOTTS), designed to provide such data for all commercial movements of Navy and Marine Corps Arms, Ammunition and Explosives (AA&E). In early 1988, NOTTS began to incorporate the emerging technology offered by commercial satellite-based tracking systems. The system has proven to be so successful that its scope was expanded in February 1989 to become a joint service ordnance tracking system, now known as the Defense Transportation Tracking System (DTTS). Effective use of this new technology has required coordination of technical and management issues between the Navy and service headquarters, the commercial munitions carrier community, and the various satellite-based tracking service vendors.

This paper will discuss the following points:

1) History of Navy transportation tracking initiatives
2) Technical description of the DTTS satellite-based system
3) Planned enhancements to DTTS
4) Technical issues requiring industry coordination
5) Future applications for satellite tracking technology

LIST OF FIGURES

ABBREVIATIONS

AA&E	Arms, Ammunition and Explosives
NOTTS	Naval Ordnance Transportation Tracking System
DTTS	Defense Transportation Tracking System
MTMC	Military Traffic Management Command
NAVMTO	Navy Material Transportation Office
TPS	Transportation Protective Service
SM	Satellite Motor Surveillance Service
SEVS	Security Escort Vehicle Service
DDPS	Dual Driver Protective Service
MSS	Motor Surveillance Service
AGS	Armed Guard Surveillance Service
SRC	Security Risk Category
LAT	Latitude
LONG	Longitude
CONUS	Continental United States
EDI	Electronic Data Interchange
Carrier	A Commercial Munitions Trucking Company
Vendor	A Supplier of Satellite Tracking Service
Shipper	A Government Activity Who Ships AA&E Via A Carrier

History of Navy Transportation Tracking Initiatives

At 4:50 a.m. on the morning of 1 August 1984, a commercial motor vehicle loaded with six MK 48 torpedoes overturned at the intersection of two major interstate

highways in the city of Denver. It was more than eight hours before the vehicle was moved to the Rocky Mountain Arsenal and the highways were reopened. The crash sparked fears of an explosion and caused what some officials describe as the worst traffic jam in the city's history (See Figure 1).

The resulting Navy investigation lead to the formation of a Naval Sea Systems Command, Special Commission on Naval Ordnance. The Commission studied the policy and procedures under which ordnance was being transported at that time focusing on commercial carriers, physical security requirements of ordnance in transit, and the need for accurate and timely shipment information in case of an accident. In all, twenty-one specific recommendations were forwarded by the Special Commission and approved by the Secretary of the Navy. One of the Commissions more significant recommendations was that in their view, due to increased hostile intelligence efforts, increased terrorist activity worldwide, and the increase in transportation incidents, that a more tightly controlled "Navy ordnance monitoring system" must be developed.

Why did the Commission feel an ordnance transportation monitoring system was so necessary? During their investigation, it became apparent that there was little or no accountability for this material while in transit. Improvements were needed to guard against theft, vandalism and the increasing problem of political protests in which unsuspecting drivers, making deliveries of explosives at Naval Weapon Station Concord, for example, were suddenly finding themselves in the midst of an anti-war demonstration. A means of identifying what material was bound for a specific activity, as well as the capability to alert the drivers, was needed to divert the shipment and prevent a possible conflict.

Public concern for hazardous materials transiting their communities was beginning to grow as well. This was made quite evident in the Denver accident. Residents were asking why are Navy torpedoes, moving from Washington state to Connecticut, going through a major populated area such as Denver and why was the Navy not better able to respond when there was a problem? (See figure 2)

The answer to these questions and more could only come about by the development of a system to better manage this material while in transit. Accordingly, on 6 June 1986 the Naval Ordnance Transportation Tracking System (NOTTS), designed to continuously track Navy and Marine Corps ordnance shipments moving within CONUS from origin to destination, became operational. This early tracking system employed a Transportation Protective Service known as Motor Surveillance Service (MSS). Upon entering unique explosive shipment information into the NOTTS database by the origin activity, a dual driver team transporting a shipment under MSS was required to place a telephone call to the NOTTS central computer tracking facility located at the Navy Material Transportation Office, Norfolk, Virginia, eight hours after departing origin to provide location and shipment status information and every eight hours, thereafter, until they reach destination, where a final call was placed to NOTTS to confirm delivery. (See figure 3).

Although the NOTTS system proved itself to be a valuable tool, it relied on drivers to place calls every eight hours to the central tracking facility which was far too labor intensive, both for the carriers and the NOTTS central tracking facility. Phone calls also increased transit time and heighten the possibility of theft or vandalism while stopped and the potential for an accident when exiting or accessing interstate highways.

Early in the development of the NOTTS system it became apparent that an inexpensive electronic means of tracking a vehicle, CONUS wide, on a nearly real time basis would be the answer to all our concerns. At that time, commercial satellite tracking technology was just beginning to emerge and appeared to offer the only CONUS communication capability. In March 1987, satellite tracking tests began using low earth orbiting (LEO) satellites that provided one-way communication from the vehicle having a four to six hour location reporting capability.

Technical Description of the DTTS Satellite-Based System

The earlier satellite testing proved to be highly successful for tracking ordnance shipments on a nation-wide basis. As the technology matured, reporting frequencies were reduced to hourly and Loran C provided vehicle location accuracy to less than a mile. In October 1988, the Army's Military Traffic Management Command (MTMC), who manages the DOD motor freight movement of materials, received direction from OSD to; 1) explore the expansion of satellite tracking and 2) reduce transportation costs through the possible elimination of existing transportation protective services.

This OSD direction meant that either MTMC must develop their own satellite tracking capability or accept the Navy's offer to team-up and expand the existing NOTTS system. After some discussion as to what the Navy had accomplished thus far and where we intended to proceed with the technology, MTMC agreed to the team approach. This arrangement was formalized between the joint services and MTMC through the establishment of a Working Group and a flag level Steering Committee. Since the satellite tracking effort had now

expanded to beyond just Navy and Marine Corps ordnance, the first order of business was to change the name from the Naval Ordnance Transportation Tracking System (NOTTS) to the Defense Transportation Tracking System (DTTS).

The next step in the process was to describe to the other services just how the DTTS system was designed to track ordnance shipments from origin to destination. (See figure 4). Prior to the establishment of DTTS, we had worked with the satellite vendors to develop a Satellite Monitoring (SM) standard which would define the specific data to be passed to DTTS, how this electronic transfer of data would be accomplished, and the degree of reliability that was expected from the carrier/vendor. Figure 5 illustrates the process of sending a message from a vehicle to the DTTS central tracking facility. The equipment located in the vehicle is designed to automatically send transmitter number and vehicle location (Loran C latitude and longitude) information on an hourly basis. The driver may send a shipment status at any time using a keyboard text message. And if the vehicle is involved in an accident or situation where the driver needs emergency assistance he would activate the single stroke panic-button which was required on all vehicles participating in SM. Messages are sent from the vehicle to a geosynchronous satellite orbiting at approximately 23,000 miles above the earth where the signal is then relayed to the satellite vendors ground station. This data is processed in the vendors computer to identify the vehicle that originated the message and is then distributed to the appropriate carriers dispatch headquarters for display and collection of location information for the entire carrier fleet. If this vehicle is transporting a DOD sensitive ordnance shipment, the hourly vehicle location data is also duplicated in the satellite vendors DTTS mailbox. Figure 6 illustrates the computer transfer of data between the satellite vendor, carrier dispatch, and the DTTS mailbox. The data entered into satellite vendors DTTS mailbox is downloaded every twenty minutes. The DTTS central computer located at NAVMTO will dial-up the satellite vendors computer, query the vendors DTTS mailbox and download the data. The vehicle data is cross referenced to the shipment entry information initially provided by the shipping activity. Thus the shipment location and status is updated hourly until it arrives at destination. At that point, the driver will send a keyboard generated arrival message and a special vendor code which the vendors computer recognizes as a signal to discontinue placement of location information for this vehicle in the DTTS mailbox. Now that we understand how the system operates, what is being done with the data from a management standpoint?

Figure 7 provides a number of benefits available to DOD through the implementation of DTTS. Not only does DTTS provide a timely emergency response capability in an accident situation, it also provides day to day shipper-receiver information to assist in workload planning. For example, based on an inbound shipment report a DOD activity may be able for the first time to anticipate the delivery day and time of specific ordnance material and arrange for the vehicle to be offloaded at a designated magazine for storage or have the material directly loaded aboard ship. The types of transportation management reports are extensive and this data is available virtually real time.

Future Enhancements To DTTS

Figure 8 illustrates several enhanced capabilities planned for the DTTS central database. These include, for example, a listing of all State Police, Explosive Ordnance Disposal (EOD) Teams and other emergency response telephone numbers. In addition, existing ordnance technical data has been added to the system which contains such information as the fire fighting code for each Navy and Marine Corps ordnance item in the inventory. This information will be passed to emergency responders in case of a vehicle accident involving explosive shipments. Other enhancements are planned for the shipping and receiving activities to permit the actual mapping of shipment locations while in transit.

Technical Issues Requiring Industry Coordination

A broad application of the DTTS technology is anticipated. Policy makers are currently looking toward the DTTS to track other hazardous materials and high value items, in addition to all DOD ordnance. The volume of these shipments, should we be directed to track them, means that the commercial trucking industry must look favorably upon a substantial investment to outfit their respective vehicles with satellite tracking equipment to accommodate this anticipated expansion. We will also be entering into discussions shortly with the carriers regarding additional driver independent safety features which will require the establishment of an industry standard vehicle sensor wiring plan. These are some of the technical issues we are presently dealing with; however, the number of incentives favoring the adoption of satellite tracking for both DOD and the carrier industry significantly outweigh these relatively minor issues.

Future Applications For Satellite Tracking Technology

Figure 9 lists a number of areas where satellite tracking would offer near term benefits to DOD. Changes are currently being staffed among the service headquarters

which would substitute satellite tracking for several more costly transportation protective services currently used by DOD shipping activities. Long-term, we can expect that satellite tracking of commercial vehicles will become the standard means of doing business. As the competition for improved customer service, market share, and the impact of regulatory requirements increase within the commercial motor carrier industry, satellite tracking will provide a significant tool to help control profitability and rates charged to the DOD for transporting an endless variety of goods.

NAVAL ORDNANCE TRANSPORTATION OFFICE


Torpedo Spill Knots Denver Traffic; Tardy Response Leaves Officials Irate

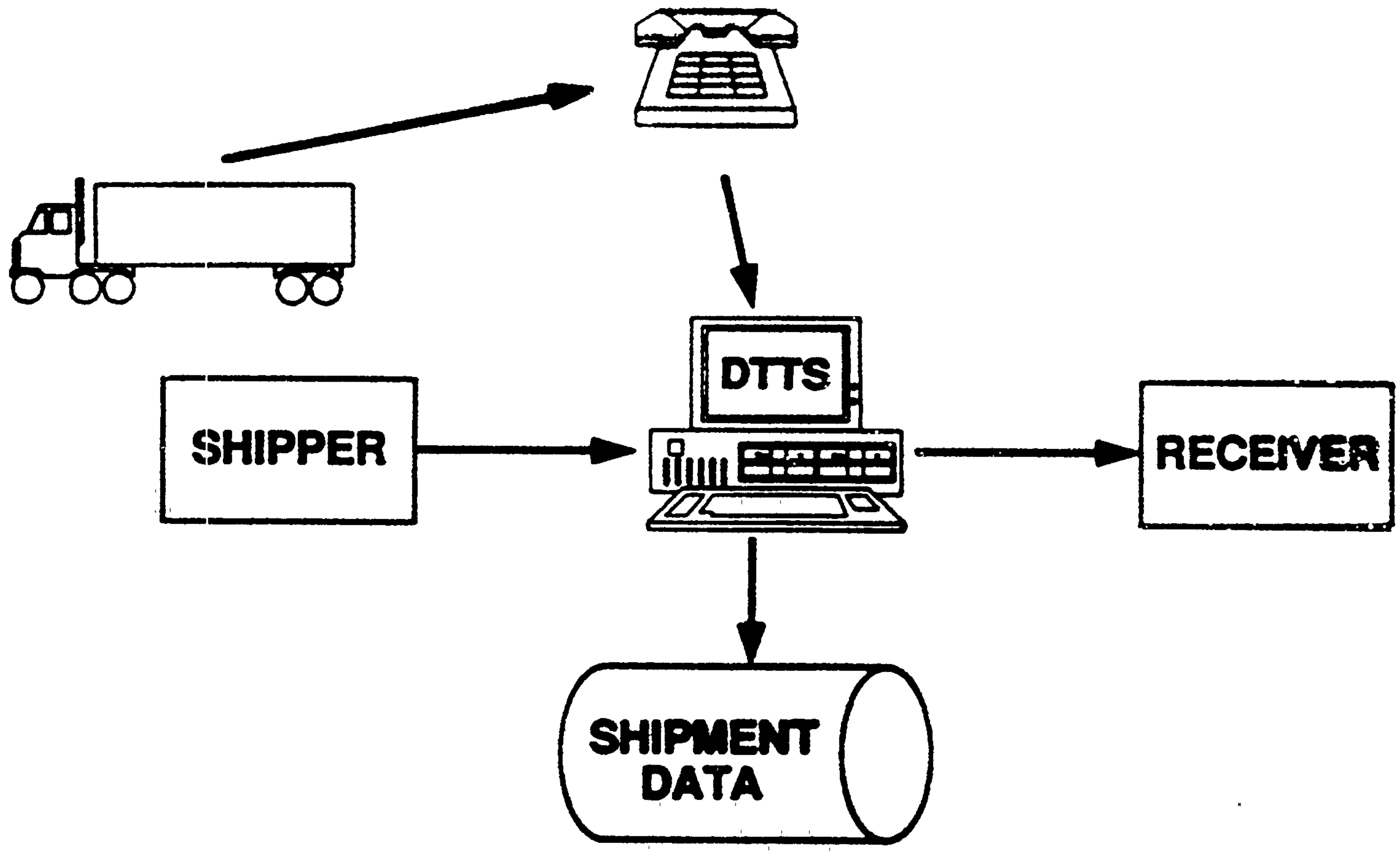
Truck Carrying Navy Torpedoes Upsets in Denver, Jams Traffic

MK 48 ACCIDENT, DENVER

WHY IS A TRANSPORTATION TRACKING SYSTEM NECESSARY?

- SECURITY
  - TERRORIST
  - THEFT
  - VANDALISM
  - POLITICAL PROTEST
- PUBLIC CONCERNS
  - ACCIDENTS INVOLVING HAZARDOUS MATERIALS
  - SAFETY
  - INCREASED RESPONSIVENESS TO PROBLEM SITUATIONS
- MONITOR OF CARRIER PERFORMANCE
  - TIMELY DELIVERY
  - ADHERENCE TO DESIGNATED ROUTES

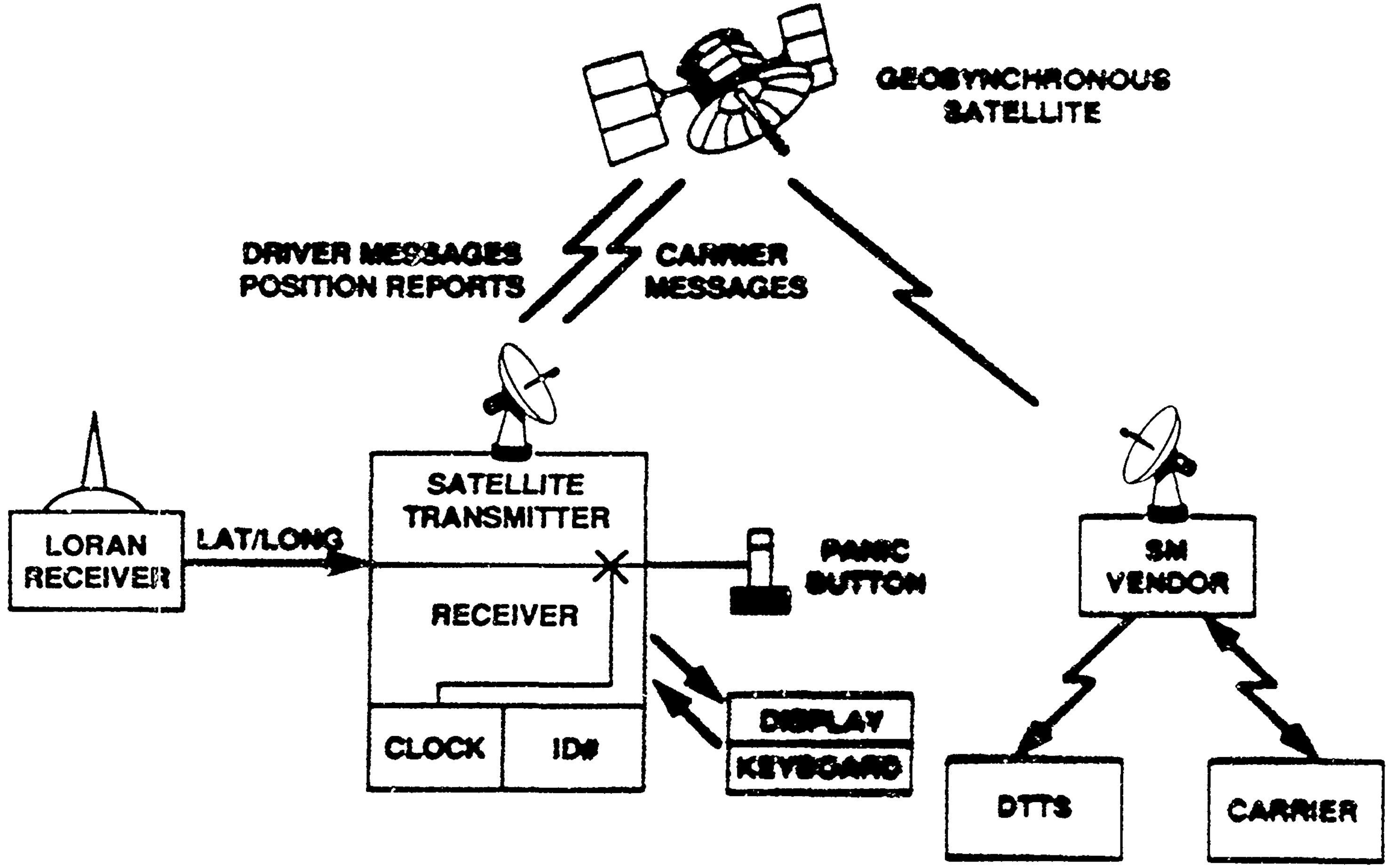
ORIGINAL SYSTEM



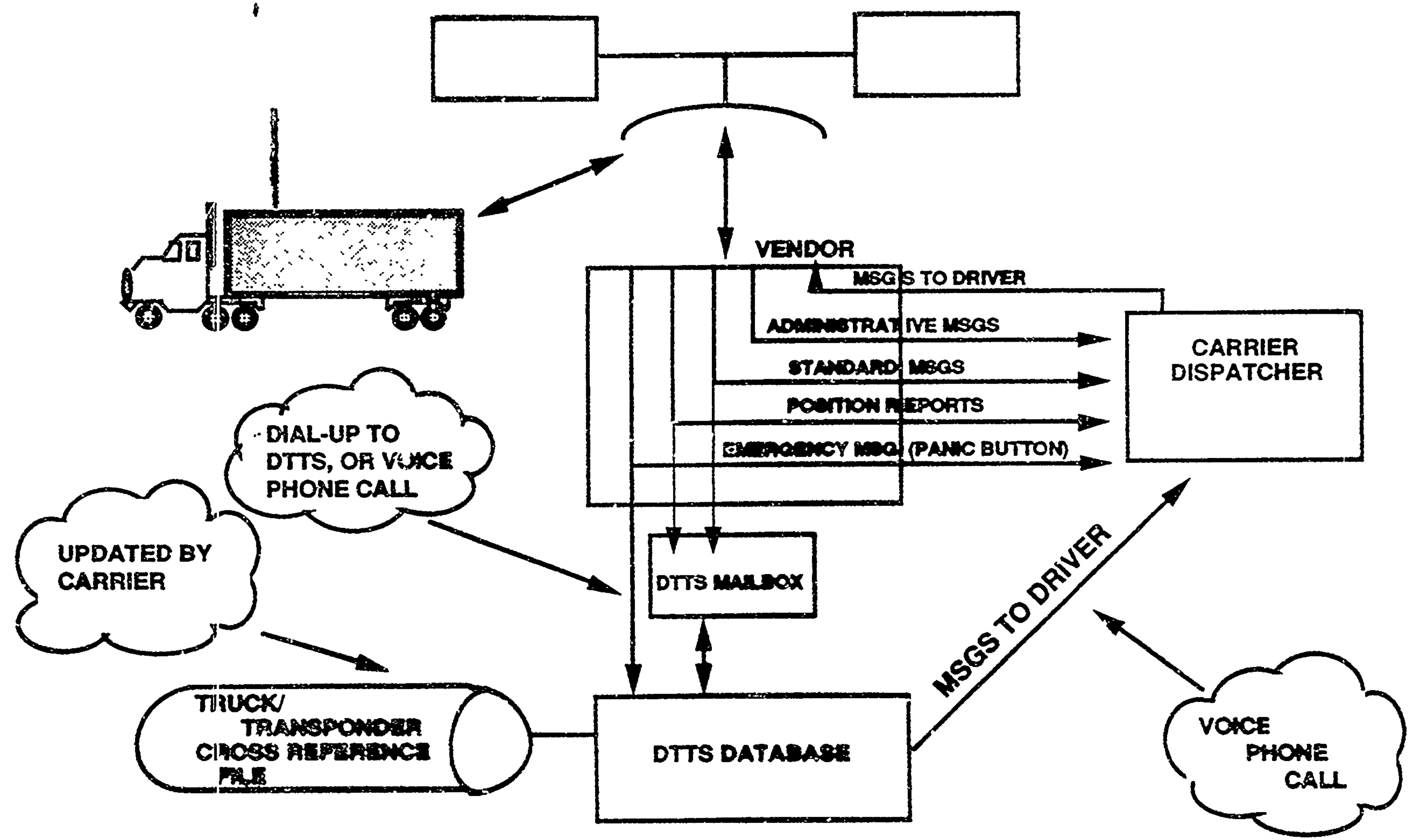
DTTS SYSTEM DESCRIPTION

- FIELD ACTIVITIES PROVIDE SHIPPING DATA TO DTTS
- DRIVER SENDS SPECIAL MESSAGE TO INITIATE SATELLITE TRACKING
- TRUCK INFORMATION (TIME, LOCATION AND STATUS) RECEIVED AT DTTS VIA SATELLITE VENDOR GROUND STATION
- DTTS UPDATES SHIPMENT STATUS
- FIELD ACTIVITIES CAN CHECK STATUS FROM DTTS AS REQUIRED
- ARRIVAL AND CLOSE-OUT DATA SENT TO DTTS BY RECEIVING ACTIVITY

SATELLITE POSITIONING



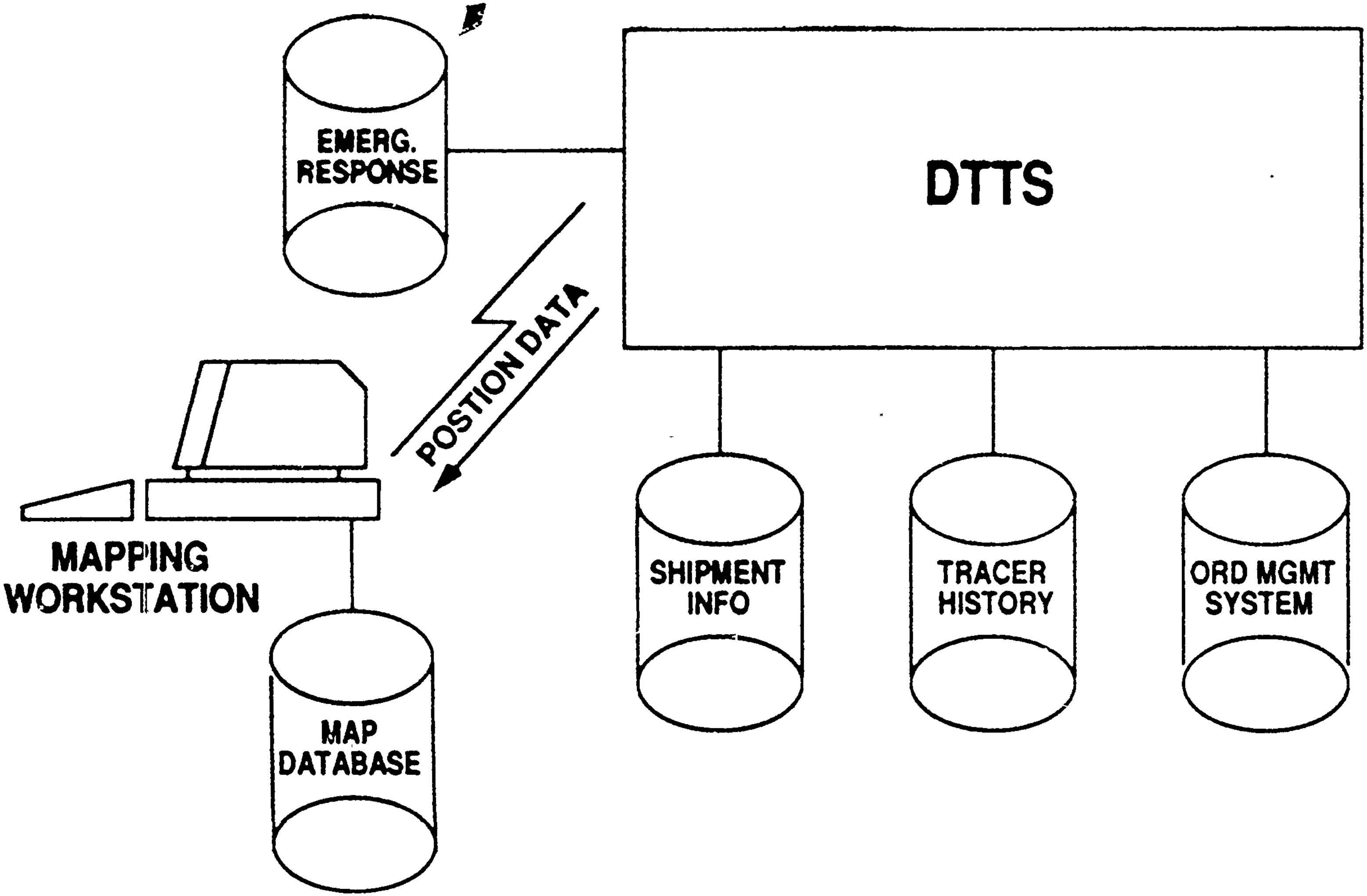
DTTS MAILBOX



DTTS BENEFITS

- EMERGENCY RESPONSE NOTIFICATION (ACCIDENT/INCIDENT)
- DIVERSION OF SHIPMENT IN ROUTE
- SHIPPER/RECEIVER WORKLOAD PLANNING (DAILY INBOUND/OUTBOUND SHIPMENT REPORTS TO WEPSTAS)
- MONITOR CARRIER PERFORMANCE
- COST EFFECTIVE FOR SECURITY RISK CATEGORY I

ENHANCED SYSTEM



DTTS FUTURE APPLICATIONS

- CURRENT
  - SECURITY CATEGORIZED MUNITIONS SHIPMENTS
  - TWO-WAY SERVICE ALL CARRIERS
  - CONVOYS
- FUTURE
  - POSSIBLE SUBSTITUTE FOR EXISTING TRANSPORTATION PROTECTIVE SERVICES
  - INTERFACE WITH OTHER TRANSPORTATION AND ORDNANCE INVENTORY SYSTEMS
  - REAL-TIME QUERY BY FIELD ACTIVITIES (MAP WORKSTATION)
  - INTERFACE WITH EDI AND GLOBAL INTRANSIT VISIBILITY SYSTEMS
  - DRIVER INDEPENDENT FEATURES - IMPACT, ATTITUDE, HEAT, ETC.
  - POTENTIAL FOR ROUTE PLANNING/ADHERENCE
  - MISSILE FUELS, OTHER SENSITIVE, HAZARDOUS, HIGH VALUE SHIPMENTS